TIMBER

ITS STRUCTURE
AND
PROPERTIES

BY

H. E. DESCH

B.Sc., M.A., [redacted]), F.R.I.C.S.

THIRD EDITION

LONDON

MACMILLAN & CO LTD

NEW YORK · ST MARTIN'S PRESS

MACMILLAN AND COMPANY LIMITED
St Martin's Street London WC 2
also Bombay Calcutta Madras Melbourne

THE MACMILLAN COMPANY OF CANADA LIMITED
Toronto

ST MARTIN'S PRESS INC
New York

PRINTED IN GREAT BRITAIN

THIS BOOK IS DEDICATED

TO

S. H. CLARKE, Esq., C.B.E., M.Sc.

IN APPRECIATION OF HIS ASSISTANCE
AND INVALUABLE CRITICISM
DURING THE PREPARATION
OF THE WORK

PREFACE TO THE THIRD EDITION

In preparing the third edition of my book, the difficulty has been to decide how much of the knowledge amassed by research organizations all over the world in the last five years should be incorporated in a work of this nature. It seemed most desirable to retain a simplified presentation of all important aspects of the subject within the compass of a single volume. I have, therefore, taken the opportunity to revise the text in several places, without greatly altering the original framework, adding only to those sections that interest a wider audience than when the book first appeared. I am particularly indebted to my Publishers for agreeing to the inclusion of several additional illustrations.

The sections on the "Classification of trees" and "Nomenclature of timbers" have been rewritten in an attempt to clarify the difficulties laymen experience with timber names. To meet the needs of students preparing for trade examinations, two pages of text figures, and brief descriptions of microscopic features used in the identification of softwoods, have been added. The chapters in Part III have been rearranged, so that the occurrence of moisture in wood, which affects most other properties of timber, is now discussed before density and strength properties.

The increasing incidence of fungal and insect activity has focussed attention on these pests of wood, and the development of several new proprietary preservatives, backed by intensive advertising campaigns, is tending to exaggerate the seriousness of the problem. The chapter on "Defects in timber" is now confined to natural defects in wood and seasoning degrade, fungi and insects being discussed in separate chapters, and a new chapter on "The eradication of fungal and insect attack" has been added after that on "The preservation of wood". This analyses the alternative curative measures in an impartial manner, which it is hoped will counter commercial advertising of proprietary products: each case is different, and there is no universal remedy.

It must be admitted that serious damage is caused by fungi

and insects, but much of this damage could be avoided were simple basic facts more widely understood and proper maintenance observed. Important as it is to cut out all decayed timber when dealing with an outbreak of fungal decay, it is not less important to trace and cure the source of moisture that created the conditions that made decay possible. The scrapping of unnecessarily large quantities of timber is all too prevalent, as is the use of large quantities of preservatives — unless the source of the moisture is cut off, "decay" reappears. Proper appreciation of the latter point would substantially reduce the cost of remedial measures, besides ensuring much better prospects of immunity in future.

As regards insects, much "wormy" timber is perfectly safe to use, and reduction of losses from *Lyctus* infestation could be effected by co-operation between timber merchants and consumers: good "yard" hygiene is of more significance than the use of large quantities of expensive chemicals. Some insect attack is essentially a "decay" problem, and attention to the cause of decay is of primary importance. For the rest, we must be vigilant in regard to the common furniture beetle, and not panic when its presence is detected: there is a greater risk that furniture will suffer a loss in value than that houses will be seriously weakened structurally by the activities of this pest. There are many excellent preservatives available to combat the furniture beetle, but the *proper application* of *appropriate inexpensive chemicals* is more important than any "*secret*" formula.

In conclusion, I would like to record my appreciation of Mr. T. W. Paddon's painstaking help in checking the proofs, and to express my indebtedness to him for his invaluable, constructive criticism.

H. E. DESCH

WOODMAN'S FOLLY, CROCKHAM HILL,
nr. EDENBRIDGE, KENT

PREFACE TO THE SECOND EDITION

Any book covering a technical field tends to be out of date before it reaches the public, and realizing this I commenced collecting notes for a revised edition while the first was still in the Press. The advent of hostilities in Malaya, culminating in the

fall of Singapore, destroyed all my notes to that date, but I secured a copy of my book a few days prior to becoming a P.O.W., and tackled a preliminary revision in the first six weeks of incarceration. I am indebted to several friends in captivity who read the text with its numerous emendations and made most helpful criticisms. In this connection I would particularly mention the help received from H. Wiseberg, Esq., C.M.G., and Dr. W. T. Quaife. Mr. Titmouse, R.E., was indefatigable in retyping the numerous amendments. In this preliminary revision I attempted to correct the more obvious shortcomings of the first edition, and to tidy the English consequent on reading A. P. Herbert's *What a Word*, given to me by my wife shortly before we married.

Release from captivity presented the opportunity for bringing out a revised edition. It was startling to discover the extent of progress in the broad field of wood technology between 1940 and 1945. Extensive revision and expansion of the text was inevitable. I am indebted to many for bringing to my notice the more important books and papers that appeared while I was out of touch with the outside world, and for the readiness with which help was extended to me whenever it was sought. As with the first edition, I am especially indebted to Mr. S. H. Clarke, M.Sc., for his valuable criticism throughout the preparation of the new text, and for reading the proofs. I have greatly appreciated the value of numerous visits to the Forest Products Research Laboratory, Princes Risborough, consequent on the facilities so readily accorded me by the Director, and for the very valuable assistance I have received from all Divisions of the Laboratory. While I am responsible for errors that remain, I wish to record my gratitude to Drs. Findlay and Fisher, and Messrs. Knight, Latham, Rendle, and Stevens, and their colleagues, for the help given to me in their respective fields, and to Messrs. McCracken and Stocker of the Library and Records Division. Messrs. Boulton and Jay and their colleagues at the Timber Development Association have given me much help with the loan of books and papers, and in tracing references. Most of the additional illustrations were prepared at the Forest Products Research Laboratory, and are reproduced with the permission of the Controller, H.M. Stationery Office. The sources of the other illustrations are acknowledged in the text.

No acknowledgements would be complete without special

reference to the help given to me, and the facilities put at my disposal, by Dr. L. Chalk of the Department of Forestry at Oxford. Dr. Chalk first aroused my interest in wood technology twenty years ago when I was one of his students, and I have been learning from him ever since those days.

In rewriting Chapter VII — "The strength properties of wood" — and in writing Chapter XIV — "Wood as an engineering material" — I owe a special debt of gratitude to Mr. P. O. Reece, A.M.Inst.C.E., A.M.Inst.M. & Cy. E., whose papers in this field are so illuminating. Mr. Reece has permitted me to use his ideas freely, and has very kindly read and criticized my text.

Sections on the influence of the micro-structure of the cell wall, stress grading, and chemical seasoning, and the chapter on wood as an engineering material, are reproduced from articles contributed to the *Timber News & Saw Mill Chronicle*, by courtesy of the editor. Mr. T. W. Paddon of the British Institute of Building Technology has been a most stimulating friend, who has placed his library at my disposal during the revision of this book, besides giving me much helpful criticism in the sections on the electrical drying of wood and adhesives.

I wish to record my appreciation of criticisms received from students who attended my lectures, based on the first edition of this book, in particular the ten ladies and gentlemen who attended my first Oxford course on timber, from whom I, and I hope the book, have benefited : the selected bibliography and the list of genera are added in response to their requests. Finally, I wish to express thanks to Mrs. S. Rush for typing numerous drafts, to my publishers for allowing me to add so many illustrations, and to the printers for the excellent work they have done from exceedingly difficult copy.

I shall appreciate suggestions from readers for improving subsequent editions.

H. E. DESCH

1B Middle Temple Lane
London, E.C.4

PREFACE TO THE FIRST EDITION

Perhaps the most important factor in modern industrial development is the growth of research: no major industry, and few individual factories, are without a research organization whose function is to improve the quality of goods produced, and to point the way for extending markets by the adaptation of products to additional uses and ever-changing demands. The timber industry has a background of long-standing empirical practice on which to draw, and it is in rather a different position from most manufacturing concerns in that it has little or no say in the production side of its raw materials, and in the ordinary course of manufacture it does not appreciably change the nature of those materials. Nevertheless timber has not escaped the prevailing trend, and is today the subject of considerable intensive research, conducted in the main under Government auspices.

The pressing need for research arose during the War, when it became imperative to accelerate existing practice, without lowering quality, and to devise methods for selecting material for special purposes with precision. The foundation of the Forest Products Laboratory at Madison in 1916 was in direct response to the American Government's needs, and, although it was not until 1930 that the scattered sections of the Forest Products Research Laboratory of England were brought under one roof at Princes Risborough, work similar to that carried out at Madison had been in progress at the National Physical Laboratory, the Imperial Institute, and elsewhere, for some years. Other laboratories devoted to the study of wood have been established in Canada, Australia, India, and Malaya, with the result that a wealth of accurate information has been amassed concerning the structure, properties, and treatment, of many timbers.

It was to be expected that some time would elapse before the industry fully appreciated the value of scientific information relating to a product so generally well known as timber, and the fact that the research was conducted by Government officers no doubt resulted in a certain amount of detachment on the part of the latter from purely practical points. The gap between the two bodies has been rapidly narrowing, as may be gauged from the astonishing growth of inquiries from trade sources received by

the laboratories in recent years. One of the difficulties has been the dissemination of the information collected: much is in language too technical for the non-scientific man, and nearly all is distributed in separate bulletins, leaflets, and reports, which do not make for easy reference to particular points. Conversations with architects, surveyors, and building contractors, convinced the author that a simple, concise account of the work accomplished by Timber Research Laboratories, and of the knowledge now available concerning timber, would be of practical value. This conviction led him to write this little book.

An account of the structure, properties, and proper handling, of wood does not lend itself to a purely popular treatment, but technical terms have been avoided as far as possible. Whenever a term appears for the first time it is printed in heavy type, and its precise meaning is explained in the ensuing passage in the text. Such words only are indexed, so that the reader may refresh his memory as to their meaning at any time by reference to the index and the relevant section of the text. A list of botanical equivalents of the trade names used in the text constitutes the Appendix.

No claim of originality for the subject matter is made: it has been compiled from standard works, and the numerous publications issued from time to time by the different Research Laboratories. It is hoped, however, that the abridgement of existing information in a simple form between two covers will be found of some practical value. Passages in the section "Worm in Timber" (Chapter XI) are based on an article of the author's in the *Timber Trades Journal*, and are reproduced here with the consent of the Editor.

The author is particularly indebted to the kindness of several gentlemen who read the text in its different stages and offered much helpful criticism and advice. Professor Garratt of Yale, and Mr. F. G. Browne of the Malayan Forest Service, read the preliminary manuscript. Subsequently, in England, the manuscript was completely revised with the assistance of Mr. S. H. Clarke of the Forest Products Research Laboratory, Princes Risborough, without whose help this book would not have appeared. Finally, Mr. B. C. Adkin of the College of Estate Management read the revised manuscript and made further valuable suggestions which have been incorporated in the text. Dr. R. N. Chrystal of the Imperial Forestry Institute has very

kindly read the proofs. The author would like to record his appreciation of this invaluable assistance, although taking full responsibility for any errors that remain.

Several of the illustrations have been especially prepared for this book, but some have been loaned from other sources. The new photomicrographs were taken by Mr. L. H. Clinkard, of the Imperial Forestry Institute, from slides loaned by kind permission of Dr. L. Chalk. The original drawings are by Mr. J. Shaw, of the Imperial Forestry Institute, and Mr. Wong See Moy, of the Forest Research Institute, Kepong, F.M.S. Figures, for which Crown Copyright is reserved, were prepared at the Forest Products Research Laboratory, Princes Risborough, and are reproduced with the permission of the Controller, H.M. Stationery Office. The sources of other illustrations are acknowledged in the text. The author would like to record his appreciation of the work of the gentlemen who assisted him in producing the illustrations, and his thanks to individuals who kindly gave their permission to reproduce illustrations that have appeared previously elsewhere.

H. E. DESCH

3 Pump Court, Temple
London, E.C.4

CONTENTS

CHAPTER IX

PART IV

CONSIDERATIONS INFLUENCING THE UTILIZATION OF WOOD

CHAPTER X

CHAPTER XI

CHAPTER XII

CHAPTER XIII

CHAPTER XIV

LIST OF PLATES

LIST OF TEXT FIGURES

PART I

THE STRUCTURE OF WOOD

CHAPTER I

INTRODUCTION

The astonishing material progress in the 20th century not infrequently results in the consumer, seeking to satisfy a particular need, being completely bewildered because the choice is so wide. The quality of the many alternatives is, however, anything but equal. The progress is the result of much painstaking research, often not directed primarily to solving particular practical problems. Research into the properties of timber is one of the most pertinent factors in enabling wood to hold its own today, second to none, for so very wide a range of quite different end-uses. The practical significance of our new knowledge of wood has, however, yet to be fully appreciated, and generally applied. It is too often assumed that generations of practical experience have taught users all there is to know about a material in such general use.

There are numerous examples extant to prove how well the aesthetic qualities of wood have been appreciated in the past. On more critical examination, however, it will often be found that much of the earlier work in wood, although unquestionably beautiful, lacks some vital quality. For example, beautiful as are the many examples of the wood carver's art in our churches and ancient buildings, their critical study often reveals that the fullest use has not been made of the especial qualities of wood — as beautiful results could have been achieved in marble or stone. The best of the modern school of wood carvers do not make this mistake: working on a much more modest scale, they make the fullest use of the grain, texture, figure, and colours of different woods to enhance the beauty of their creative work, which could not be so successfully achieved in other materials. Similarly, the architects of past ages who designed the many elaborate forms of hammer-beam trusses or framed floors reveal that they did not fully appreciate the strength properties of the material

with which they worked: unnecessarily large sections of timber were frequently used. Exceptionally, *vide* Plate 3, the apparently heavy beams are not sufficiently large for the span and loading conditions. In the example illustrated, the main beams are suitable for a safe working load of only 20 lb. per square foot, whereas the joists could carry a load of 60 lb. per square foot, and the flooring twice this figure. Such ill-balanced designing gives rise to "failures" in service, and brings wood into ill-repute, besides being extremely uneconomical. The modern architect, fortified with the research worker's data, can span much greater distances than his predecessors, with much less material, and, by using modern glues, can achieve shapes and forms no less beautiful than the earlier craftsmen's work. In effect, if the best and most economical use of wood is to be made, all the properties of the material require to be studied carefully, and used in the most appropriate manner (Plates 4 and 5).

It is always possible to recognize a piece of oak or mahogany, and to distinguish between these two timbers; it is not so readily apparent that no two pieces of the same timber are exactly alike. The great variation in structure is part of the charm of wood, making it suitable for widely different uses, but, in certain circumstances, it places timber at a disadvantage in competition with other more uniform materials. To use wood to the best advantage, it is necessary to understand its structure, and to know how and why that structure varies. This can best be done by seeking answers to such questions as: What is wood? How is it formed? And what purpose does it serve in the growing tree?

It is obvious that wood is produced by trees, not because of its usefulness to man, but because of its function, at one stage in its existence, as an integral part of a living plant. A study of the functions of wood in the life of trees is helpful in explaining the limitations and scope of timber as a useful material for so many different purposes, and will be found to justify the seemingly academic approach to practical problems adopted in the early chapters of this book.

THE TREE

Since Darwin first advanced his theories regarding evolution, it has become generally accepted that man has developed from

PLATE I

Mother and child by E. J. Clack illustrating the use of grain and figure of wood in a work of art

From a carving by E. J. Clack, by courtesy of the Editor of "Wood"

PLATE 2

Reclining figure by Henry Moore illustrating the use of the grain and figure of wood in the modern sculptor's work

Henry Moore's "Reclining Figure 1935–36" by courtesy of the sculptor

more primitive ancestors, and that he represents the highest form of development in the animal kingdom. In the same way, advanced plants have evolved from earlier forms of plant life. Moreover, just as in the animal kingdom, we find primitive types existing side by side with the more advanced today.

To the botanist, trees are more primitive than herbs, because the tree habit, or form of growth, is less efficient for maintaining the existence of a species. In Nature there is a continuous struggle between individuals for survival, and in the long run it is only the more efficient that prevail. Fitness for ceaseless competition depends on rapid reproduction of individuals to make good the inevitable losses sustained in such competition. Most herbs grow from seed and develop and produce new seed in a single season, whereas trees require several seasons to mature, before reproducing their race. The production of a massive stem uses up much energy, which in herbs is devoted to the reproduction of the species. In consequence, it may be inferred that, but for man's interference, the more effective "economy", and rapid reproduction of herbs, would result in their effacing trees from the earth, although the process might well take millions of years.

Another aspect of the struggle for survival, of considerable practical importance to those concerned with the growing of timber, is the struggle between individual trees for the same area of ground, and the air space and light above. The forester makes use of the natural tendency of plants to compete against their neighbours by growing his trees just close enough to obtain the maximum volume of good-quality timber. The importance of the competition between individuals in producing clean, straight timber may readily be appreciated if the shape of a tree grown in park-land conditions be compared with one of the same species from high-forest: the former makes little height growth, and branches near the ground, whereas the latter is tall and straight, and the bole is clear of branches to a considerable height. From the economic standpoint, the forest-grown tree produces a greater volume of better quality timber than the park-land tree.

The tree habit, then, is a mode of growth assumed by certain plants to enable them to outwit their neighbours in the struggle for air and light, which is essential to the development of an individual, and its subsequent duty of reproducing its kind. It

is not the most efficient mode of growth from the plant standpoint, but it results in the production of timber useful to man.

CLASSIFICATION OF TREES

Some trees belong to more primitive plant-types than others, giving rise to different classes of commercial timbers; all are the successors of still earlier forms of plant life, although the lines of development to the present-day representatives are rarely clear-cut, being more often suggestive of evolution along parallel lines from several common ancestors. Commercial timbers fall into two main groups, the "**softwoods**" and "**hardwoods**", and the trees that produce these two different classes of timber are themselves quite distinct. The former are **gymnosperms**—**conifers** or cone-bearing plants, characteristically with needle-shaped leaves and naked seeds; the latter are **dicotyledons**—broad-leaved plants, characteristically with broad leaves and seeds enclosed in a seed-case. Dicotyledons with **monocotyledons** (grasses and palms) constitute the **angiosperms.** Although the division into "softwoods" and "hardwoods" is a convenient one for differentiating two broad classes of timber, there are a few timbers, *e.g.*, pitch pine, among the softwoods that are actually harder than other timbers classed as hardwoods, *e.g.*, balsa, lime, willow. Further, the divisions are not always applied correctly, particularly in the tropics. For example, native softwoods in such regions are usually soft "hardwoods", that is, they are broad-leaved species with soft wood, although they are frequently referred to as "softwoods"; true "softwoods" often do not occur in such localities.

Botanists early found the need for an orderly system of naming plants. They recognized that, although no two plants might be identical, minor variations between similar individuals did not alter the fact that several such individuals had many features in common, not shared by any other groups of plants, and these "features in common" were reproduced in successive generations of such plants. This gave rise to the botanical concept that all plants could be separated into different **species.** It was also observed that several species shared certain "features in common"—that is, they were more like one another than they were like other species. This gave rise to the second fundamental botanical concept of a **genus.** Recognizing the validity

PLATE 3

A framed floor: the apparently substantial beams are suitable for a safe working load of only 20 lb. per square foot, whereas the joists could carry a load of 60 lb., and the floor boards twice this figure

FIG. 1. Sheet laminated portal frames 42 ft. span

U.S. Forest Products Lab. Service Bulletin

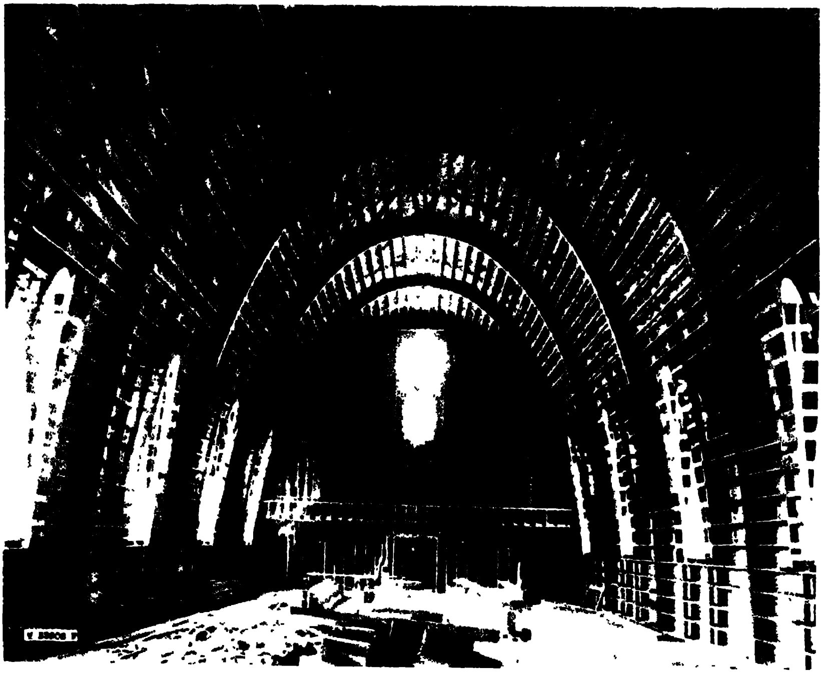


FIG. 2.—Church showing span of 42¾ ft. rise 40 ft.; spacing of glued lamina arches 14 ft.

U.S. Department of Agricultu

of these two concepts led botanists to adopt the binominal method for plant nomenclature, the first part of the botanical name indicating the genus to which the plant belongs, and the second part the species. Botanists have subsequently attempted to adopt a natural system of classification, based on evolutionary lines, arranging groups of similar genera in **families**, and bringing related families together into **orders**. The difficulty of reconciling all the complex factors that have to be considered has resulted in the systems of classification being arbitrary, rather than natural. Mistakes have occurred through placing an evolutionary significance on some feature that had no such significance, and through failing to recognize a significant feature or features as such. Developments in the study of wood anatomy over the last thirty years, and the closer collaboration between wood anatomists and systematic botanists that has resulted, are helping to clarify difficulties. Parallel development from common ancestors, and the disappearance of some of the links in the evolutionary chain, however, give rise to real difficulties that may well be incapable of final and complete solution. Nevertheless, from the practical standpoint, the important fact emerges that every plant has one **botanical name**, made up of two parts, the first indicating the genus and the second the species. These names are, by general consent, in Latin.

Unfortunately, the position is not quite so simple as the foregoing paragraph suggests. A tendency of 19th-century botanists to name plants from inadequate material, the occurrence of actual errors of observation, and differences in interpretation of specific or generic characters, resulted in botanists not always being in agreement as to the correct botanical name of a plant: in consequence, some plants have been given more than one botanical name, and two or more different plants have been given the same name. Errors of observation arise through a failure to recognize the significance of some types of variation in morphological characters: "immature" leaves, *e.g.*, the leaves of seedlings or even saplings, are often much larger, and very different in shape, from the leaves of a mature tree of the same species. Working with too little material, and seeing only sapling leaves, a botanist may make the mistake of thinking he is confronted with a "new" species, which he proceeds to name and describe, whereas the species has already been named from

mature leaves, or *vice versa*. Poor laboratory technique is responsible for actual errors of observation: the parts of a flower may be so broken or torn in dissecting that the "evidence" is misinterpreted. Real differences of opinion as to the correct interpretation to be placed on observed variation in morphological characters are yet another source of confusion in plant nomenclature. Certain morphological features of plants with a relatively wide geographical range may exhibit considerable variation when specimens from the extreme limits of distribution are compared: in such circumstances it may well be almost a matter of personal opinion where to draw the dividing line between two very similar plants. This is perhaps a rather special case of variation, but it may help to underline the fact that differences in interpretation of morphological variation are likely to arise, and result in some botanists splitting what was previously considered a single species into several separate species, or, conversely, combining several formerly "distinct" species into one species.

Rules for naming plants are open to less ambiguity, and are now regularized by accepted international procedure. The botanist receives dried specimens, called **herbarium material**, for study; it should consist of leaves, flowers, and fruit, but is seldom so complete. He has first to decide whether it is undescribed, that is, unnamed material, or whether it is additional material of an already described species. If the former, the botanist next has to satisfy himself whether the "new" species can be regarded as another species of a known genus, or whether it is so distinctive as to necessitate establishing a new genus too. If it is a question only of a new species of an established genus, choice of a suitable specific name alone rests with the botanist, but when a new genus also has to be established, both generic and specific names are selected by the botanist "describing" the plant. In selecting names, botanists have an entirely free choice, although it is usual either to adopt a word descriptive of some morphological character of the plant, or to commemorate the place, collector's name, or native name in the name chosen. The only obligation on the botanist is to Latinize the name or names he selects. To complete his task, and give the name validity, the botanist has to prepare a description of the new plant — in Latin — following long-established precedents as to the morphological data to be recorded, when the description is published in a recognized

TS SHOWN THUS + TO BE MADE WITH 2½" DIA.
BER CONNECTORS (ONE AT EACH INTERFACE)
OLT WITH WASHERS.

HUS ⊐⊠⊏ TO BE 6" LONG SECURELY SPIKED BETWEEN MEMBERS.

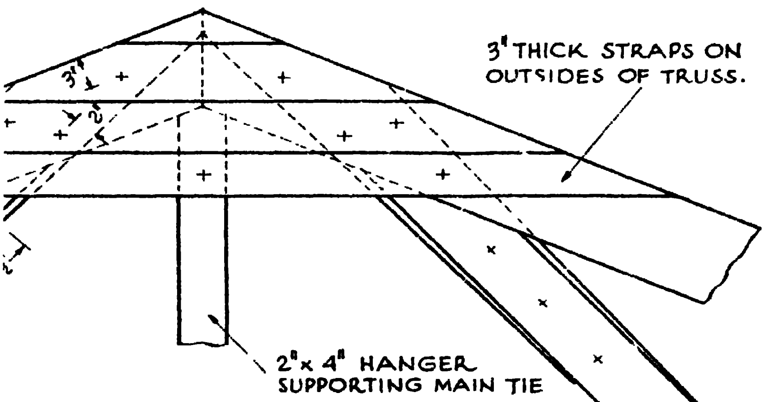
0 lb PER □' ON SLOPE DEAD LOAD.
7 " " " " LIVE "
2 " " " WIND ON VERTICAL WALL INCREASES FOR DEAD + LIVE
LOAD ALLOWED IN ACCORDANCE WITH B.S. CODE OF PRACTICE.

DIRECT LOAD	700 lb PER □"	
FLEXURE	880 " " "	
SHEAR	100 " " "	
SSION ACROSS GRAIN	150 " " "	
END BEARING	900 " " "	

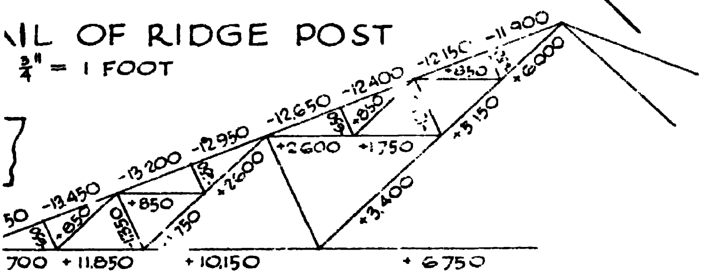
ND CLEARANCES SHOWN ON DETAILS MUST BE STRICTLY
ILARGED DETAILS CAN BE ADAPTED TO JOINTS NOT DETAILED.

BE SPLICED WHERE NECESSARY. THE RAFTER PREFERABLY IN A
CENTRAL PURLINS

PROVIDED IN BOTTOM CHORD.



IL OF RIDGE POST
¾" = 1 FOOT



CES IN MEMBERS FOR DEAD LOAD OF 10 lb PER □' ON SLOPE
CES IN lb TENSION + VE COMPRESSION - VE.

SBESTOS CEMENT	DRAWN BY	CHECKED BY	3. 5 1951
ES AS SHOWN.	DRAWING No. D.C.R. 515.		

botanical journal. The material on which the description is based is recorded in this published description. Thereafter, provided the botanist has been correct in recognizing a new species, and has allocated it to its appropriate genus, the name he has selected becomes the valid botanical name of the species. In citing this name in future, the describing botanist's name or initials follow the selected name. This convention is a most important part of a botanical name, since it links the name with the authority for the name, and minimizes confusion later should the botanist have made a mistake.

Internationally accepted rules have been drawn up for dealing with the types of mistakes that do arise in the naming of plants: the essence of these rules is that when errors are detected the earliest name recorded in the literature must be revived and later names discarded, but, if the earlier name should refer the plant to the wrong genus, then only the earlier specific name is retained. Transference of a plant to another genus may necessitate the selection of a new specific name if the original specific name has already been used for another species in that genus. There are also rules regarding the use of capitals in specific names: place names should not be capitalized, only vernacular names and the names of people. Foresters have adopted the practice of de-capitalizing all specific names, but botanists have not accepted this departure from their rules. Critical workers today are constantly finding that two or three supposedly different plants are identical, or that some well-known botanical name must be dropped and an earlier, and obscure, name revived. This is apt to give the impression that botanical names are distinctly fluid, whereas the fault lies with botanists who have been too ready to describe and name plants from inadequate material, without searching the literature sufficiently thoroughly. It does indicate, however, that it is by no means always a simple matter to discover the correct botanical name of a species, and such names should be used with caution, and never without their authenticating authority.

NOMENCLATURE OF TIMBERS

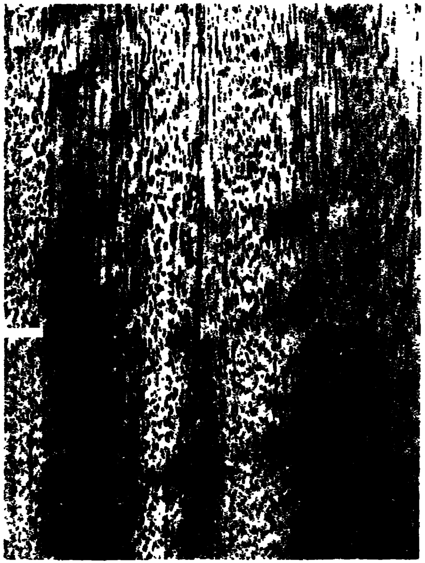
It is not suggested that timber names present as complex problems as do botanical names, but there are nevertheless very

real practical difficulties to be solved in selecting entirely satisfactory timber names. The precision essential in botanical work is seldom necessary in timber names, nor would it usually be practicable, because several botanically distinct species often provide a single commercial timber. Botanical names have the added disadvantages of being in a foreign language, often difficult to pronounce, and undesirably long. Moreover, it is sometimes more necessary to distinguish between the timber of one species from different localities, than it is to distinguish between the timbers of different species. An example of this is the timber of the two common species of oak, *Quercus robur* L. and *Q. petraea* Liebl., that occur both in the British Isles and in Europe. The timbers of the two species cannot be distinguished from one another on anatomical grounds, or by other identifying characters, but material from the richer soils of the south of England is suitable for very different purposes from that grown on poorer soils at higher altitudes in central Europe: for commercial purposes the two types are distinct timbers. In primitive communities, the problem is readily solved by the local inhabitants choosing words from their own tongue or dialects: these are **vernacular names.** Since the local inhabitant is not as critical an observer as the scientific botanist, vernacular names are rarely as precise as botanical ones; they often refer to more than one species, and they may on occasions be applied to quite different species because of some superficial similarity in form between distinct plants. These objections are not of serious practical importance so long as there is little movement of timber from district to district, but the position is very different in a market drawing its supplies from many different localities or even countries. Even in a small country dialects change from district to district, so that the vernacular name in one locality may be very different from that in another. This may lead to confusion in a distant, importing market. Nomenclature difficulties are further complicated by the deliberate hiding of the true identity of a timber under a **"trade" name**, often that of some well-established timber, with the addition of a geographical or other qualifying, but sometimes misleading, adjective.

Some examples may assist the reader in clarifying the problem in his own mind. For example, the true oaks, beech, and sweet chestnut belong to one family, the *Fagaceae*; the oaks con-

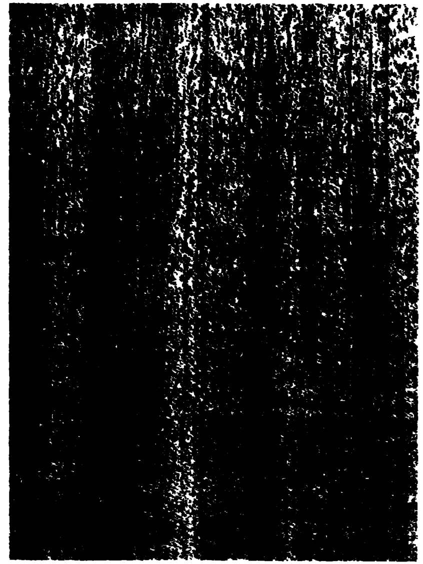
PLATE 6

TYPES OF COMMERCIAL MAHOGANY

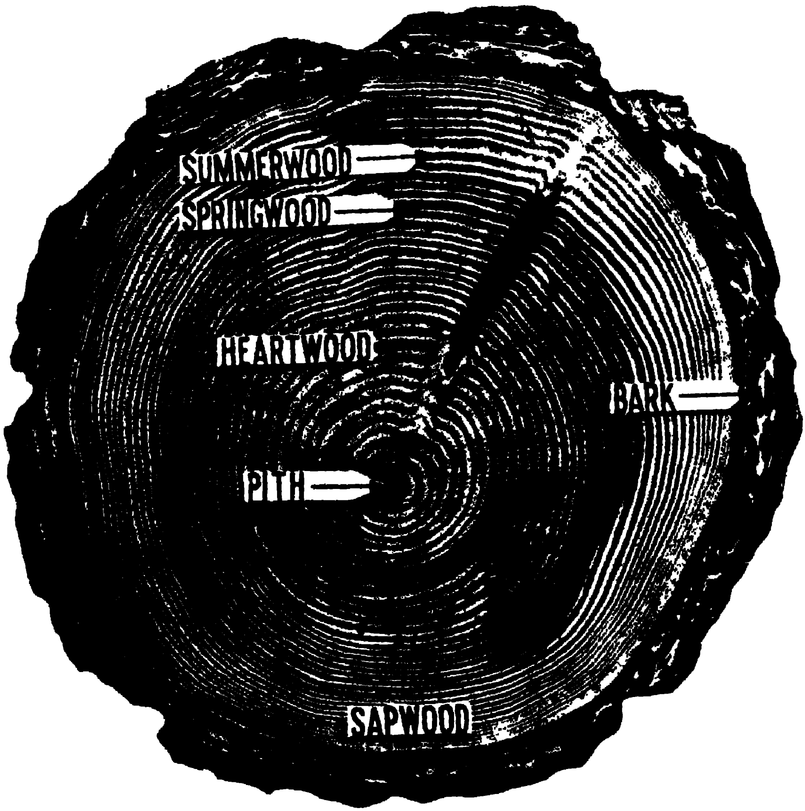


meranti—any one of at least 20 species of *Shorea*. Wt. per cu. ft. 30 to 45 lb. Shrinkage from green to 12 per cent. M C · Tangential 4·5 ; radial 1·9

Central American mahogany—*Swietenia macrophylla*. Wt. per cu. ft. 34 lb. Shrinkage from green to 12 per cent. M C · Tangential 2·6 ; radial 1·9



African mahogany—principally *Khaya ivorensis*. Wt. per cu. ft. 35 lb. Shrinkage from green to 12 per cent. M,C Tangential 2·5 ; radial 1·8



Cross section of softwood log showing bark, wood, and pith

By courtesy of the Canadian Forest Serv

stitute one genus, *Quercus*, beeches a second, *Fagus*, and the true chestnuts a third, *Castanea*. The different kinds of true oak, *e.g.*, American red oak, American white oak, Turkey oak, are separate species of the genus *Quercus*. This is a simple case in which trade practice follows botanical classification closely, although different countries have different names for *Quercus* timber: in Britain it is oak, whereas in France it is chêne, and in Germany Eiche. When vernacular names are of the popular type absurdities may occur: the standard trade name adopted for *Eucalyptus regnans* F.v.M. is mountain ash in Australia and Tasmanian oak in the United Kingdom, but this timber has also been called swamp gum in Tasmania and Australian oak in Victoria; it is neither a true ash nor a true oak. Such anomalies are the outcome of European emigration: settlers name plants sometimes because of similarities of tree form or habit, sometimes because of colour similarities in the timbers, and sometimes because of other associated ideas. When the same species occurs over a wide area several names, based on these different concepts, may come into being.

The Malay Peninsula provides examples of confusion, arising from differences in meaning of vernacular names in different parts of the same country, which is accentuated by reason of a single trade timber being produced by several distinct botanical species, each with one, and sometimes more than one, vernacular tree name. A common source of *red meranti* in the Peninsula is the tree known to botanists as *Shorea leprosula* Miq. This tree, in the forest, is called *meranti tembaga*; its timber is sold in most parts of Malaya as *meranti*, and in Singapore as *seriah* (pronounced *seraya*). *Seraya*, on the other hand, is the tree name of another species of *Shorea*; as a timber name in certain parts of the Peninsula it refers to the produce of several tree species that yield a grade of timber superior to common *meranti*. *Meranti* exported to the United Kingdom has to compete with a commercially similar timber from the Philippines called *lauan*, thereby confusing the importer and the layman. Both Malayan *meranti* and Philippine *lauan* may be offered for sale as Philippine mahogany, when the layman is not only confused but deceived.

The practice of borrowing names of familiar timbers, and applying them to other and quite distinct woods, is at the root of much confusion in timber nomenclature. It frequently misleads

the layman to the extent of causing him to use timbers for purposes for which they are unsuited. Alternatively, he may be induced to buy timbers that, were he more enlightened, he would not purchase, or, if he did consider them, he would not be prepared to pay the prices asked. It has been computed that the name "mahogany" has been applied at some time or another to the timbers of more than two hundred distinct botanical species, and the name is in common use today for several distinct groups of timber. The original "mahogany" of commerce was the so-called Spanish mahogany obtained from San Domingo and other West Indian islands then owned by Spain; Central American mahogany is a very close relative, being the timber of a different species of the same genus, *Swietenia*, but it is a very much milder timber to work than the original Spanish mahogany. African mahogany, on the other hand, is produced by several species of two different, but related, genera (*Khaya* and *Entandrophragma*), belonging, however, to the same family as the American species of *Swietenia*. Philippine mahogany is produced by several species of more than one genus belonging to a different family altogether, the *Dipterocarpaceae*. In consequence, timbers bearing the name "mahogany" vary appreciably in their appearance and properties, and in the opinion of the author some have no real claim to be considered in the same class as true mahogany (Plate 6). Similar confusion has arisen through the widespread use and misuse of such names as walnut, ash, oak, and teak, leading in some instances to lengthy and costly litigation between the sponsors of distinct timbers sold under the same trade name.

Attempts are being made to standardize trade names. The British Standards Institution, for example, has published a list of standard names for timbers known to the U.K. trade, *vide* B.S. 881 and 589. The Standards Association of Australia has issued a similar list for Australian timbers, *vide* A.S. 5.0.2–, and so has the Forest Research Institute, Dehra Dun, for Indian timbers. Publication of a list does not, of course, solve the problem of timber nomenclature, but it points the way. It has not yet been possible to compile a list based entirely on internationally acceptable rules; compromise has been necessary. The ideal solution would be the adoption of standard names on an international basis, whereby each trade timber would have a

single unambiguous name. Persistence in the present confusion may well result in several potentially useful timbers being discredited, besides perpetuating deception of the laymen. It could give rise to much expensive and acrimonious litigation, such as has marred relations for several years in the different sections of the American "mahogany" trade. Every timber worth putting on the market is entitled to a name of its own; it does not need to masquerade as something else. Conversely, within the English-speaking world, the same "commercial" timber does not require half a dozen names, merely because of different geographical sources of supply. In the absence of general agreement regarding timber names, the existence of a difficult problem must be recognized: "standard names" are used throughout in the text, but to assist the reader the botanical equivalents are given in Appendix II

DIVISIONS OF THE TREE

Almost all plants with which we are familiar have three main parts: **roots, stems, and leaves.** The characteristic that separates trees from other woody plants is that they have a single main stem, the **trunk** or **bole.**

Each of the three parts is specially adapted to a particular function: the roots anchor the plant in the ground, and take in water and mineral salts in dilute solutions from the soil: the stem conducts these solutions from the roots to the leaves, it stores food materials, and it has mechanical rigidity, supporting the leaves above competing vegetation: the leaves absorb gases from the atmosphere and, with the energy obtained from sunlight, manufacture complex substances for carrying on the life processes (Fig. 1).

The timber user is interested primarily in the trunk or bole. This bole has an outer covering, called the **bark**, which protects the wood from extremes of temperature, drought, and mechanical injury. The inner layers of the bark conduct the food manufactured in the leaves to regions of active growth, and into places where it can be conveniently stored. The bark, being a conductor of food materials, is often rich in chemical substances, such as tannin and dyes derived from plant metabolism.

Between the bark and the wood is a thin, delicate tissue, known

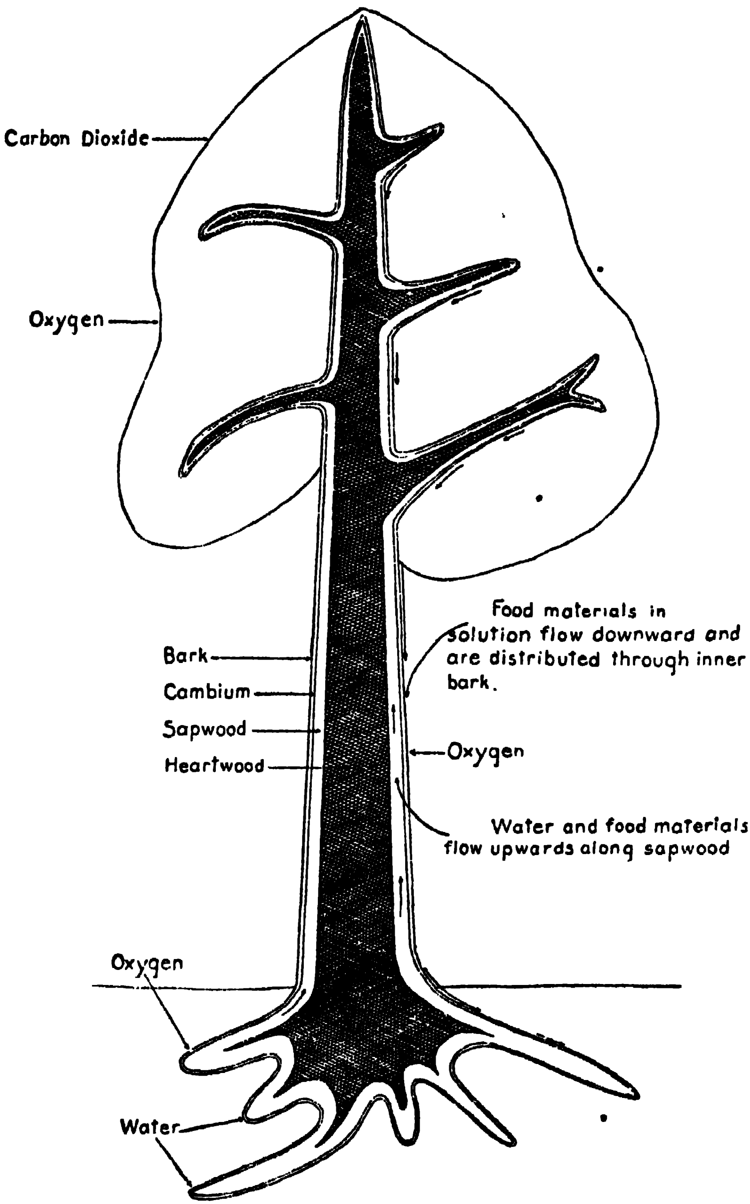


FIG. 1.—Diagram showing main parts of a tree and how food is manufactured and distributed

By courtesy of the Canadian Forest Service

as the **cambium**, which forms a complete, glove-like sheath covering the bole and branches. This tissue produces bark towards the outside and wood towards the inside of the tree, and the enlargement in girth of the trunk is brought about entirely by the activity of the cambial sheath. The production of wood and bark tissue occurs only when the cambium is growing: in temperate regions this is during the spring and summer months. In this period the bark may easily be peeled, because the cambial tissue is then less rigid and more easily torn than during the non-growing seasons, when it is tough and strongly attached to the bark and wood tissue.

DIVISIONS OF THE STEM

Under the bark is the cylinder of wood, and in the centre of this cylinder is the **pith** (Plate 7), which may be up to ½ in. in diameter, but in many trees is barely visible. A cross section of a branch is similar to that of the main stem, but that of a root differs in having little or no pith.

If the end surface of the bole is planed, further details of the wood structure can be seen: the wood of trees grown under seasonal conditions consists of a series of concentric layers of tissue, called **growth rings** (Plate 7). Each **growth layer** comprises the wood produced by the cambium in a single growing season. The rings are actually layers of wood, extending the full height of the tree, a new layer being added each growing season, like a glove, over the whole tree. Thus the wood nearest the outside of the bole is the youngest. In temperate regions, and certain tropical countries, the alternation each year of a growing season, followed by a resting period, results in the growth rings being annual rings, thus providing a fairly accurate means of computing the age of a tree after it is felled. Double (or multiple) rings, consisting of two or more false rings, caused by serious interruptions to growth during the growing period, sometimes cause errors in such calculations. Where growing seasons are not well defined, as in many tropical regions, growth rings may be indistinct and they may not be annual, but, as in seasonal climates, new wood is formed in concentric layers.

Growth rings are apparent because the wood produced at the beginning of the growing season is different in character from

that formed later in the season, and zones of **early wood**[1] and **late wood**[1] may be distinguished. Where this is the case the early wood is softer, coarser, or more porous, than the late wood.

The work of food storage and sap conduction is performed in most trees only by the outer, or youngest, growth layers ; these are known as the **sapwood.** The sapwood forms a distinctive zone, which may be from half an inch up to several inches wide, depending on the species and age of the tree, and the mode of growth of individual trees. Trees of the same age and species have a wider zone of sapwood when grown in the open than when grown under forest conditions in close competition with other trees. The central part of the tree is concerned with providing mechanical rigidity to the stem and support for the crown ; it is known as **heartwood.**

The sapwood is usually lighter in colour than the heartwood and less durable, and, when green, contains much more moisture. The line of demarcation between the two zones may be sharply defined or indefinite, and in some species there is no colour differentiation between the two : such trees are popularly spoken of as "all-sapwood" trees, although this is not an accurate description. In many trees the conducting channels are blocked in various ways when the wood becomes heartwood, and any remains of stored food material become changed to tannins and other substances ; it is to these changes that the durability of the heartwood may be ascribed. In the absence of colour differences such changes are the only indication of transition to heartwood.

THE UNITS COMPOSING WOOD

In common with all living tissue, plant or animal, wood is built up of individual units called **cells.** These units are either tube-like, with blunt or pointed ends, or brick-shaped. They may be empty or they may contain various kinds of solid or semi-solid substances. Cells differ considerably in size and shape, and each is adapted to one or more of the three primary functions of the stem. The majority are invisible to the naked eye, varying from 0·001 to 0·02 in. in their largest dimension.

The formation of cells is a "vital" or "living" process, which

[1] The early wood is sometimes called springwood, and the late wood, summer- or autumn-wood.

we describe as " growth ", the increase in size of plants being brought about by the formation of additional cells much more than by the enlargement of existing ones. Growth in plants is restricted to regions where cell-forming tissue occurs. The main stem and branches of a tree increase in length solely at their tips,[1] and growth in thickness occurs in the sheath of cambial tissue, one or more cells thick, situated between the bark and wood. Growth in thickness continues after height growth has practically ceased, and up to the time the tree dies.

New cells arise as a result of repeated division of the cambial cells. Before division occurs these cells swell, and certain changes take place in their contents. Partition walls are then formed, either in the longitudinal, oblique, or horizontal planes, dividing each cell into two. The longitudinal division provides the cells of the bark and wood, and the oblique or horizontal division adds cells to the cambial sheath, necessitated by the increase in circumference of the bole as growth proceeds. The two cells that result from longitudinal division are identical at first, but their subsequent development is different. One, after enlargement to the size of the original cambial cell, resumes the function of these cells, and divides again, while the other develops into either a unit of the **secondary xylem** (wood tissue) or a unit of the **phloem** (bark tissue). The two cells resulting from oblique or horizontal division of a cambial cell merely increase to the size of normal cambial cells, and then undergo longitudinal division in the normal manner to form bark or wood cells as described above.

The secondary xylem is the timber of commerce, and our study will be confined to the cells that compose it. These cells develop rapidly after formation, completing the process in a few weeks, after which the majority die and undergo no further change in size or shape. Those that remain alive assist in growth, *e.g.*, by storing food, and when no longer required for this purpose they also die. In other words, the bulk of the stem and branches of a living tree is composed of dead cells.

[1] The growing tip of the main stem and branches is composed of (1) meristematic cells of the apex and (2) the **pro-cambial strands** derived from normal meristematic cells and situated immediately below the growing tips. Growth in length is brought about by activity in the region of the pro-cambial strands. These strands give rise later to isolated patches of cambial cells that eventually link up to form the cambial sheath.

When first formed, the young cell is in a plastic condition, and capable of considerable increase in size and change in shape, rather like a partially inflated balloon. Increase in size and change in shape are rapid, and when the final size is attained the walls are thickened by the addition of further layers of wall substance laid down from the inside of the cell. The original unthickened wall is called the **primary wall**, and the layers added afterwards constitute the **secondary wall** (Figs. 2 and 3).

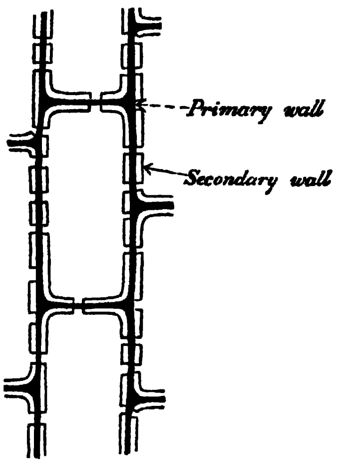


FIG. 2.—A cell showing the primary and secondary walls (much enlarged)

Unthickened areas, called **pits**, are left in the primary wall during the formation of the inner layers, and these serve as means of communication between cells: liquids moving in the tree pass mainly through the pits. The pits of different types of cells show modifications in their structure, which sometimes increase their efficiency in controlling the movement of liquids into and out of the cells (Fig. 3, II). As might be expected, conducting cells have more pits than those concerned merely with the provision of mechanical rigidity, and the pits are specially adapted for controlling the movement of liquids in these cells.

Unlike most of the other structural features discussed, pits are a " laboratory feature ", visible only with the aid of a microscope in thin sections of wood, or specially prepared slides.

With the formation of the secondary walls, chemical changes occur that increase the rigidity of the walls. Among the substances formed is **lignin**, which gives its name to the process: **lignification.** Lignification should not be confused with the changes that take place in the transition from sapwood to heartwood. Lignification is dependent on the cell being alive, whereas changes occurring in the transition from sapwood to heartwood can take place in dead cells, since they are confined to changes in the contents of the **cell cavity** (the space enclosed by the cell walls), and to the addition of infiltrates to the cell wall that do not alter the chemical composition of wall substance itself.

We have learned that the stems of trees perform three functions, and that these different functions are carried out by different types of cells. A group of similar cells performing the same function is called a **tissue**; thus we may speak of the storage tissue, the conducting tissue, and the mechanical or strengthening tissue.

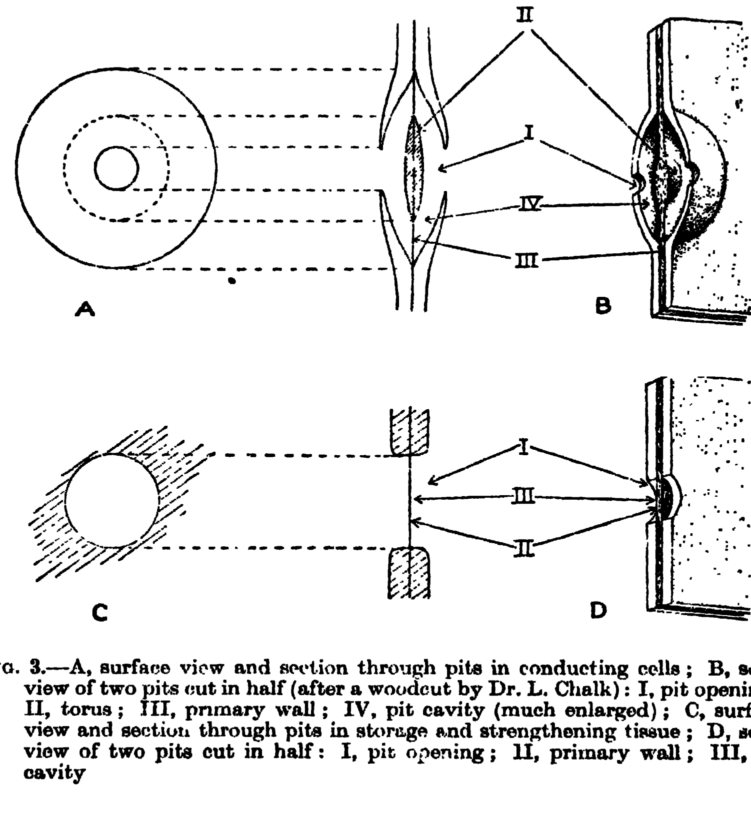


FIG. 3.—A, surface view and section through pits in conducting cells; B, solid view of two pits cut in half (after a woodcut by Dr. L. Chalk): I, pit opening; II, torus; III, primary wall; IV, pit cavity (much enlarged); C, surface view and section through pits in storage and strengthening tissue; D, solid view of two pits cut in half: I, pit opening; II, primary wall; III, pit cavity

THE COMPOSITION OF CELL WALLS

Cell wall structure is decidedly complex, but as a result of the combined efforts of physicists, chemists, and botanists in recent years, we now possess a reasonably clear picture of the fine structure of the plant cell wall. A complete picture is still impossible: visible and ultra-violet light permit of accurate and direct observation of particles larger than 2500 Å,[1] and X-rays

[1] 1000 Å = 0·1 μ; 1 μ = 0·001 mm.

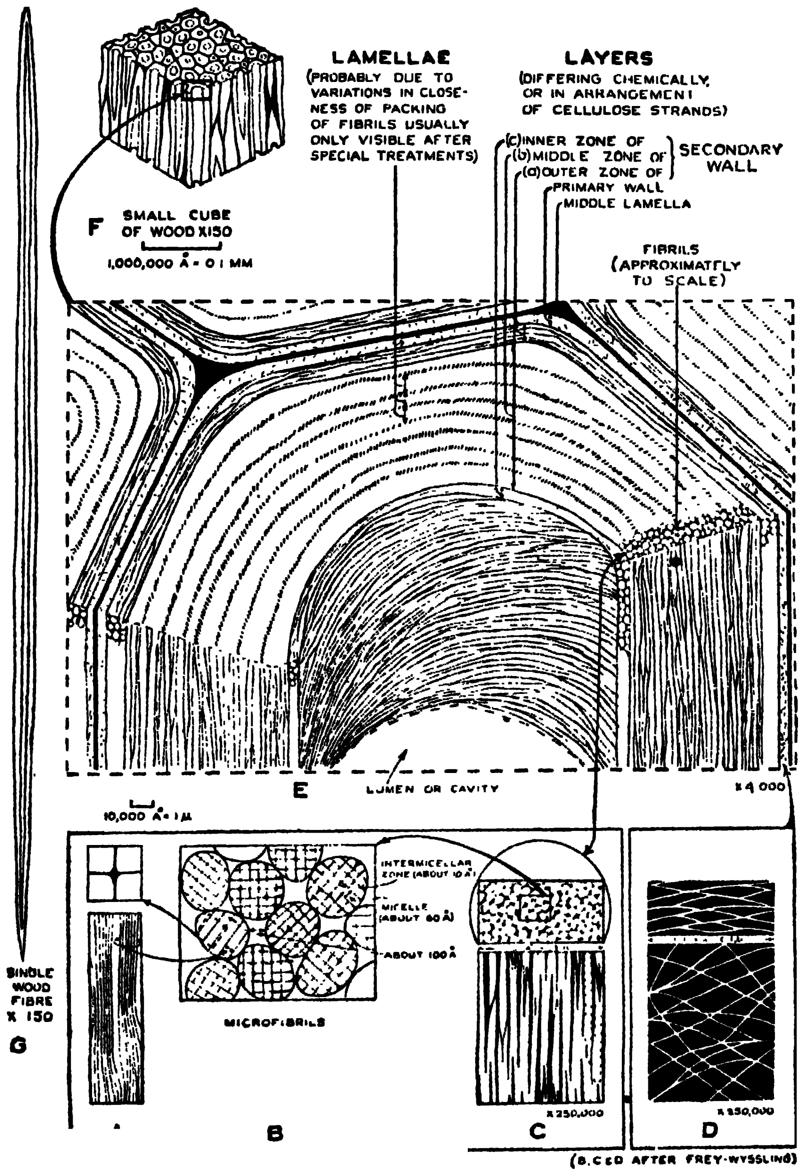


FIG. 4.—Diagrammatic representation of cell wall structure (for legend see facing page)

Drawn by Miss M. S. Smith, and reproduced by courtesy of the Director, F.P.R.L., and the Editors of "Nature"

FIG. 4.—**Diagrammatic representation of cell wall structure**

A. **Cellulose chain-molecules, showing here and there zones of regular and parallel arrangement (the micelles indicated by X-rays).**

B. **Group of microfibrils, showing approximate relative sizes of micelles and spaces revealed by study of material impregnated with silver.**

C. **Cellulosic and non-cellulosic systems in the secondary wall. Cellulosic white, non-cellulosic materials black; transverse section above, longitudinal section below. Large circle indicates approximate size of fibril at same magnification. (Note that the dimensions given by the author of Figs. B and C do not correspond exactly, but they serve to indicate the approximate sizes. The linking arrows have been inserted by the author of the paper from which this figure is taken.)**

D. **Cellulosic and non-cellulosic systems in the primary wall. Cellulosic white, non-cellulosic materials black; transverse section above, longitudinal section below.**

E. **Small piece of wood, showing the relative sizes and dispositions of the cell wall constituents as revealed by microscopic examination.**

F. **Small cube of wood fibres magnified 150 times.**

G. **Single wood fibre magnified 150 times.**

Fig. 4 is from a paper entitled "Fine structure of the plant cell wall", by S. H. Clarke, published in *Nature*, No. 3603, pp. 899-904, November 1938, and subsequently reprinted as F.P.R.L. Special Report, No. 5, 1939: *Recent work on growth, structure, and properties of wood.* This paper is a most authoritative survey, with a comprehensive bibliography, which the reader wanting to pursue the study of cell wall structure should not fail to read. The account given in the first paragraph on page 18 reduces an extremely complex subject to a skeleton outline essential to the understanding of certain phenomena to be discussed later.

This concept of cell wall structure is based on direct microscopic examination, aided by staining reagents, to the limits of resolution of the compound microscope (up to × 1000 linear magnification), inference between × 1000 and × 15,000, and X-ray studies above × 15,000. Microscopic examination reveals:

1. The **middle lamella**, which is shared by adjacent cells, and differs chemically from the other cell wall layers.

2. The **primary wall**, which is laid down during extension growth — that is, after division of the cambial initial, when the new xylem cell is increasing in size and changing its shape.

3. The **secondary wall**, which is the thickening material added after extension growth is finished; it may be differentiated into at least two zones; the layer labelled "inner" in Fig. 4 is sometimes not distinguishable.

The cell wall is composed of cellulose and other constituents, the relative proportions of which vary in the different layers and lamellae. The lamellae can be dissected into fibrils — threads of cellulose, the direction of which, with reference to the main axis of the cell, may vary in the different layers. The fibrils can be dissected chemically into fusiform bodies.

The fibrils are composed of microfibrils, which are aggregates of micelles. Micelles are aggregates or bundles of cellulose chain-molecules. The long chain-like molecules form the framework of the cell wall, and have been compared with the steel rods of reinforced concrete. They are mainly parallel with each other, but between them are many ultramicroscopic spaces — intermicellar zones — which are capable of holding water and other substances. Some theories attribute shrinkage and swelling to the movement of water from and to these intermicellar spaces.

make it possible to study only details of much smaller dimensions; between these limits is a gap that can only be filled by inference and conjecture (Fig. 4). Reduced to simple terms, our present knowledge may be summarized as follows: the cell walls of all plants may be visualized as series of thin, concentric layers or sleeves. The individual layers are composed of spiral, thread-like strands, known as **fibrils** (Fig. 5), which may be likened to valve springs making one or more turns in the length of a cell. The fibrils in turn are composed of minute, spindle-like units, **fusiform bodies** (micro-fibrils), which may be dissected into small **spherical units.** The ultimate composition of the spherical units are the molecules of cellulose, a substance composed of carbon, hydrogen, and oxygen.

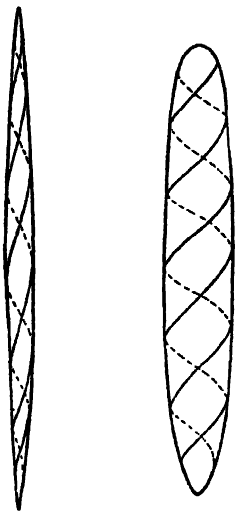


FIG. 5.—Diagrammatic drawing showing the spiral alignment of fibrils in the cell wall. Note the difference in pitch of the spirals in A and B

By courtesy of A. Koehler, Esq.

The purest form of cellulose in plant tissue is cotton; actually the hairs of the cotton seed, which are individual cells. In the cells of wood, cellulose is associated with other substances, the most important of which is lignin. To this latter substance wood owes its stiffness. Nevertheless, the cellulose of wood is chemically identical with that of cotton, and various methods are employed commercially to remove the other constituents of the cell wall, leaving a fairly pure form of cellulose. The resultant substance is the raw material of the chemical paper-pulp and artificial silk industries.

In addition to cellulose and lignin, which are the main constituents of the cell walls of *all* woods, other substances, spoken of as **infiltrates**, are present in the cell walls and cell cavities of *some* woods. These infiltrates have an important bearing on problems of utilization. For example, tannin renders the heart-wood of oak durable, and black-coloured infiltrates are responsible for the decorative appearance of ebony. On the other hand, absence of such infiltrates is of great importance to the manufacturers of paper-pulp and artificial silk, and the presence of gums and resins may adversely affect the working and painting

qualities of timber. Even in extreme cases, however, infiltrates rarely exceed 10 per cent. of the dry weight of wood, and more usually account for only 2 to 3 per cent.

The chemical composition of cell walls influences strength properties, working qualities, and utilization of timber, and the physical structure explains certain other properties of wood, *e.g.*, electrical conductivity and insulating properties, and its behaviour in relation to changes in atmospheric conditions.

CELL CONTENTS

In addition to the "living" content or **protoplasm** of all living cells, **crystals** of calcium oxalate (Fig. 6, *a* and *b*), deposits of **silica** (Fig. 6, *c*), and plant food materials may occur in the storage

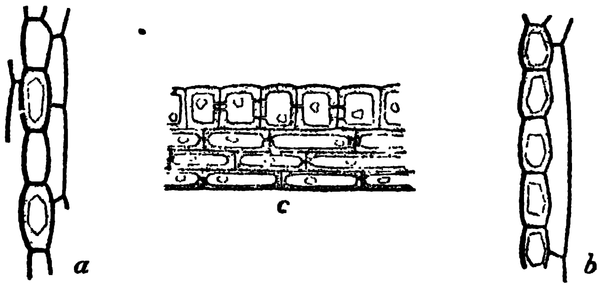


FIG. 6.—*a* and *b*, crystals in wood-parenchyma cells; *c*, deposits of silica in ray cells

tissue of both sapwood and heartwood, and gums and other solid deposits in the vessels of the heartwood. Plant food materials are of particular importance, because in some forms they are the food of certain insects and fungi that attack wood, and in other forms they are repellent to such foes. For example, starch, which only occurs in any quantity in the sapwood, is an essential food of powder-post (*Lyctus*) beetles and sap-stain fungi, and the aromatic oils that occur in the heartwood of some timbers are toxic to fungi and insects.

The foregoing pages have dealt with problems of nomenclature and the structure of wood in outline; the next two chapters deal in greater detail with the structure of the different kinds of cells of which wood is composed. As the tissues of softwoods are simpler in many respects than those of hardwoods they are described first.

CHAPTER II

SOFTWOOD TISSUES

GENERAL CONSIDERATIONS

Cells have been described as being tube-like, with blunt or pointed ends, or brick-shaped, but when examining wood with a lens or under the microscope it is seldom possible to see the cells in more than one plane at a time. It is, however, important to keep in mind when examining a piece of wood that cells have three dimensions, and that their appearance in the three different planes may be different (see Plate 8). In other words, in a given section of wood, any one cell will be viewed in one of its three planes, and its appearance will depend on whether that plane presents a cross section of the cell or a longitudinal view; the longitudinal view may be radial-longitudinal or tangential-longitudinal, the cell itself being seen either in section or in elevation. There are therefore five different, alternative views: one in cross section or plan, one in radial-longitudinal elevation, one in radial-longitudinal section, one in tangential-longitudinal elevation, and one in tangential-longitudinal section. Differences between longitudinal sections and elevations of individual cells are, however, rarely discernible with the naked eye or an ordinary hand lens. At the outset of a study of wood anatomy, it is often difficult to appreciate that a given cell may present different appearances on the cross, radial, and tangential sections of a piece of wood, and until this is realized it may be difficult to understand illustrations. In the ensuing pages the different types of cells are described as individual units, but for the most part they are illustrated in one plane at a time, and in association with other cells of the same or of a different type, as they actually occur in wood. Individual cells can be separated out by **maceration**: thin shavings of wood are boiled in a solution of potassium chlorate in nitric acid (commercial acid diluted in 50 per cent. of water),

PLATE 8

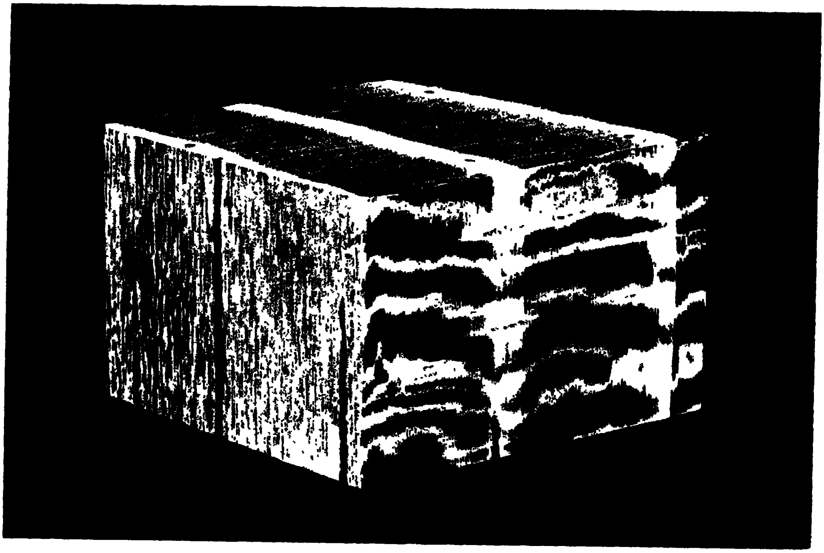


FIG. 1. A cube of softwood magnified

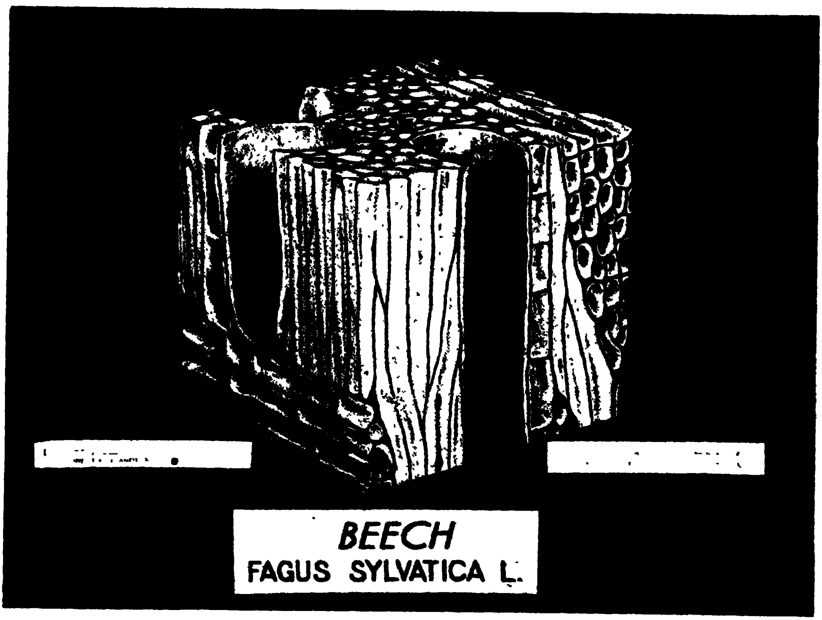


FIG. 2.—A cube of hardwood highly magnified

Photos by F.P R.L., Princes Risborough

PLATE 9

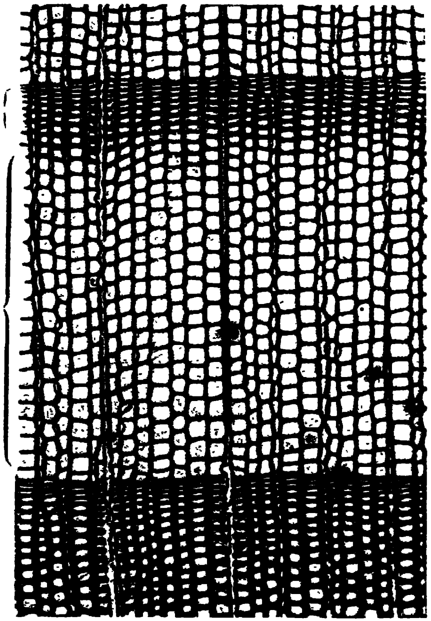


Fig. 1.—Transverse section of Scots pine (× 75) showing one complete growth ring. Note the thin walls of the early wood tracheids and the thick walls of the late wood, and the abrupt change from early to late wood

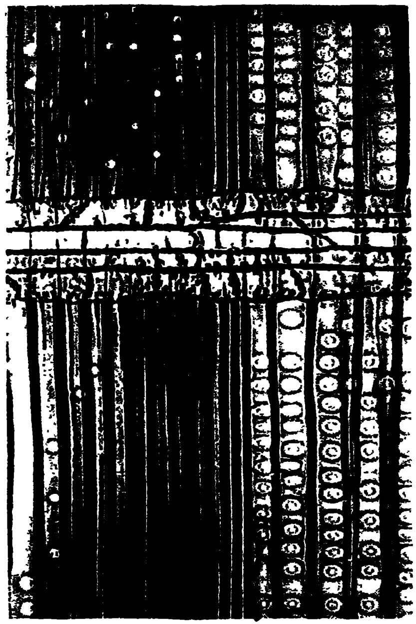


Fig. 2.—Radial-longitudinal section of Scots pine (× 150). Note the numerous and large pits in the early wood, and the few small pits in the late wood

Fig. 3. Tangential-longitudinal section of Scots pine (× 150). Note the small pits in the late wood (x) and the resin canal in the ray (y)

Photos by L. A. Clinkard

which allows of the individual cells being teased apart with mounting needles, and the separate cells, suitably stained and mounted on slides, being examined under the microscope.

THE CONDUCTING AND STRENGTHENING TISSUES

In softwoods the conducting and mechanical functions are performed by a single type of cell, each unit of which is known as a tracheid. These cells are hollow, needle-shaped units attaining as much as 0·4 in. in length, but more usually varying from 0·1 to 0·2 in. They are packed closely together so that a cross section through them resembles a honeycomb (Plate 9, fig. 1).

Examination of Plate 9, fig. 1 reveals differences in thickness of cell walls and in the size of cell cavities. It will readily be appreciated that the larger the cavity the better is the cell fitted for conduction, and, conversely, the thicker the walls and the smaller the cavity, the less suitable is that cell for this purpose, but the better is it fitted for strengthening purposes. In the tree the thin-walled tracheids with large cavities are primarily concerned with the conduction of sap, and the thick-walled ones with maintaining mechanical rigidity, although the latter may also play some part in conduction. Radial sections of softwoods show a second modification of structure between the thin- and thick-walled tracheids (Plate 9, fig. 2). In this figure it will be seen that the pits in the thinner-walled, conducting tracheids are larger and more numerous than those in the thicker-walled tracheids that function as strengthening tissue.

If we turn to Plate 9, fig. 1 again, a further and conspicuous feature of the wood structure of softwoods may be noticed. The distribution of thin- and thick-walled tracheids is not haphazard : the thin-walled conducting tracheids are laid down at the beginning of a growing season, when the water requirements of the leaves are at a maximum, whereas the thick-walled strengthening tracheids are formed later, giving rise to alternating zones of thin- and thick-walled cells. This arrangement, incidentally, renders growth rings in softwoods conspicuous to the naked eye ; the early wood, containing a smaller proportion of wall substance, appears lighter in colour than the denser late wood. In some species the transition from thin- to thick-walled tracheids is

abrupt, *e.g.*, larch, Douglas fir, European redwood, but in others *e.g.*, white pine and the true firs, it is gradual.

The quality of a softwood depends largely on the proportions of thin- to thick-walled tracheids, and on the contrast between the wood of these two zones. The higher the percentage of late wood the stronger is the timber; moreover, marked differences in thickness of the walls of the early and late wood cells may cause the two zones to behave differently under tools and in service, and may give rise to painting problems, *e.g.*, as in Douglas fir.

In popular language tracheids are often called "fibres", particularly in connection with wood-pulp in the paper industry, but this is incorrect, as true fibres occur only in hardwoods.

THE STORAGE TISSUE

The storage tissue is known collectively as parenchyma; it consists of two kinds of cells that are essentially similar in details of structure, but that differ in their manner of distribution in the wood. These cells are brick-shaped, with the longer axis horizontal in the **ray-parenchyma** cells, and vertical in the **wood-parenchyma** cells. The cells have relatively thin walls with numerous pits. They differ from tracheids in remaining alive for some years after their development is completed. This is because plant food is usually stored in some form other than that required by the growing cambium, and its conversion to a suitable state can only occur in a living cell. When no longer required for storage the parenchyma cells die like any other cells of the secondary xylem.

The ray tissue occurs in narrow, horizontal bands or plates called **rays** (medullary rays), which radiate outwards from the centre of the tree to the bark, although on a small area from near the outside of a large tree they may appear as a series of parallel layers between several rows of tracheids as in Plate 9, fig. 1. These plates of tissue are continuous outwards because the cambial cells from which they arise produce only ray cells at each division, and never wood-parenchyma cells or tracheids. As a tree increases in girth, additional groups of specialized cambial cells are formed that produce only ray cells. In this way the number of plates of ray tissue per unit length of circum-

PLATE 10

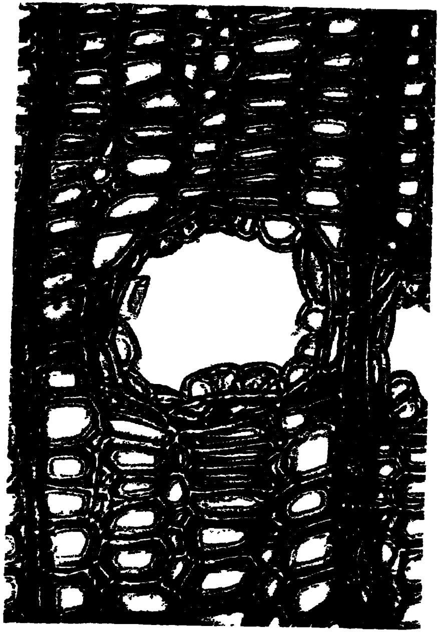


FIG. 1. Transverse section of Scots pine (about ×300) showing a vertical resin canal

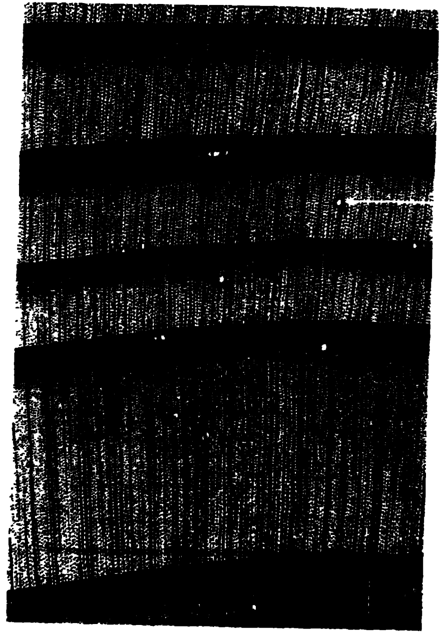


FIG. 2. Transverse section of larch (×10) showing normal distribution of vertical resin canals

Photos by L. A. Clinkard

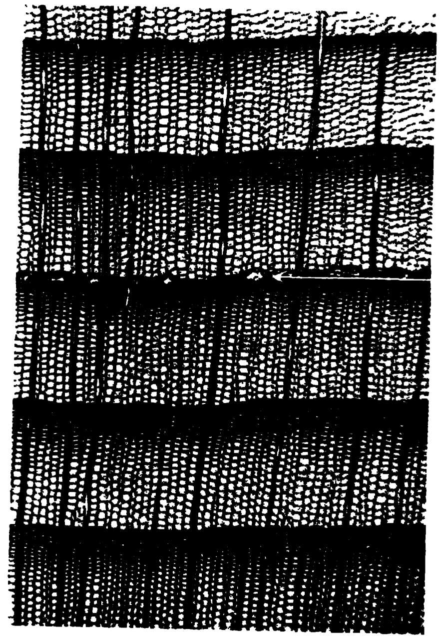
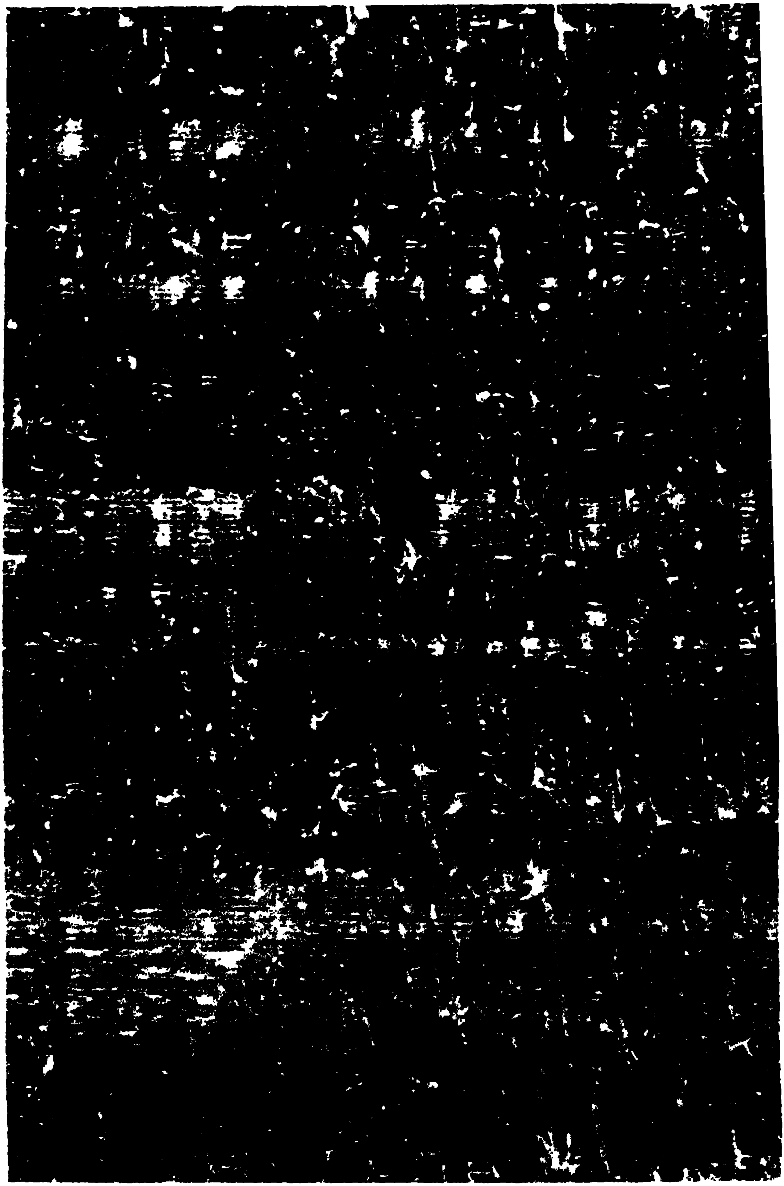


FIG. 3.—Transverse section of cedar (×10) showing a tangential series of traumatic resin canals

Photo by F.P.R.L., Princes Risborough

PLATE 11



Scalariform perforation plates in the vessel members of American whitewood ($\times$ 40), as seen on a radial face of the wood

Photo by F.P.R.L., Princes Risborough

ference of a stem remains approximately the same, irrespective of the age of the tree. The number of rays per unit of circumference, however, varies appreciably in different species: from less than one to more than ten per millimetre of circumference. The use of the term "medullary ray" should be avoided: medulla is an alternative term for pith. Hence, only those rays that originate in the first year's growth, or pith, are strictly medullary rays; such rays cannot be distinguished from those that originate later in the life of a tree and, therefore, are not true "medullary rays".

The rays are usually just visible to the naked eye on radial surfaces, where they appear as narrow, horizontal ribbons 0·002 to 0·02 in. wide (Plate 9, fig. 2). They may appear discontinuous because the cut surface is rarely truly radial and the rays may run out of the section.

On end and tangential surfaces the rays can usually be seen with the aid of a low-power lens. On end surfaces they appear as narrow lines radiating outwards, crossing the growth rings at right angles, and on tangential surfaces (Plate 9, fig. 3), where the rays themselves are seen in section, they appear as short, vertical, boat-shaped lines.

The wood-parenchyma cells are derived from normal cambial cells that also produce tracheids. After longitudinal division of a cambial cell, the cell that is to become a unit of the storage tissue divides transversely, one or more times, to give a vertical series of cells. The individual cells are wood-parenchyma cells, and the series is known as a **parenchyma strand.** Several strands may be united end to end.

In softwoods the wood-parenchyma tissue is sparse in amount, and usually visible only under the microscope. The strands are scattered through the wood, or restricted to definite zones, or in a layer at the end of a season's growth. In the last-mentioned case, the layer is usually visible to the naked eye on end surface as a narrow line, lighter in colour than the surrounding tissue.

RESIN CANALS AND "PITCH POCKETS"

A characteristic feature of many softwood timbers is their resinous nature, which is often sufficient to give them a pronounced odour, and may cause freshly sawn timber to be "tacky".

The resin is formed in parenchyma cells, and in some species occurs in special channels called **resin canals** or **resin ducts.** These canals are not cells, but cavities in the wood, lined with an "**epithelium**" of parenchyma cells. The epithelial cells secrete resin into the canals.

Resin canals run vertically in the stem and horizontally in the rays; they are just large enough to be seen with the naked eye. They are a useful feature for distinguishing some timbers, since they are always present in some species, *e.g.*, the larches, Douglas fir, the true pines (Plate 10, fig. 1), and spruces, but they are normally absent in others, *e.g.*, the true firs, sequoia, and yew.

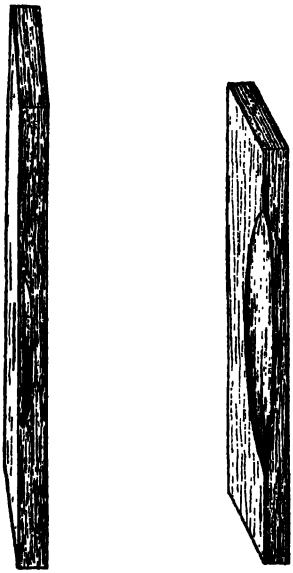


FIG. 7.—Pitch pockets in Douglas fir (considerably reduced)

Vertical resin canals may develop, as the result of injury to the tree, in timbers from which they are normally absent, as well as in those in which they are a normal characteristic. Such canals are said to be **traumatic**; they differ from normal canals in that they occur in short or long rows parallel to the growth rings (as seen on transverse section), whereas the normal canals are scattered in distribution (compare Plate 10, figs. 2 and 3).

Serious injury to the cambial cells may result in the formation of "**pitch pockets**" (Fig. 7). These vary in size from about $\frac{1}{8}$ in. to several inches wide tangentially, and up to a foot or more longitudinally. They are saucer-shaped, with the concave face towards the pith, and up to an inch or more at their greatest depth radially. They contain liquid resin, which flows out readily when the pockets are sawn through. Openings of the wood along the growth rings may also become more or less filled with pitch in a liquid or granulated state: these are known as **pitch seams** or **pitch shakes.**

MICROSCOPIC FEATURES

Early and late wood tracheids, and wood- and ray-parenchyma cells, are the only types of *cells* that occur in softwoods, but certain distinctive types of cell-wall thickening, and the shape and distribution of pits, characterize the anatomical structure of the woods of different genera, providing the only positive means of identification. Hence, although these features have no bearing on the practical utilization of the timbers concerned, nor can they be used diagnostically except in the laboratory, they are of some importance even to the strictly practical user, and require defining here.

Tracheid pittings.—The bordered pits of tracheids typically occur in one or two rows, as seen on radial sections (fig. 2, Plate 9 and Text fig. 8, *c*), but, in the *Araucariaceae* particularly, the pits are distinctly angular in outline, and the pits in one row alternate with those in the rows above and below, *i.e.*, **alternate pitting**, instead of being arranged in parallel lines, one above the other (Fig. 8, *b*). Yet another variation in distribution of pits in tracheids is their occurrence, mainly in rows of three, the pits in one row being immediately above and below those in the adjacent rows, *i.e.*, **multiseriate** and **opposite pitting** (Fig. 8, *c*).

In *Cedrus* the margin of the torus, as seen in radial section, is regularly scalloped (**scalloped tori**), providing a reliable diagnostic feature for distinguishing the genus (Fig. 8, *d*).

Ray tracheids.—The ray cells of some softwoods are of two kinds — ray parenchyma and **ray tracheids**. The latter are not parenchyma cells, but mechanical tissue and physiologically inactive; they are equipped with bordered pits, which can usually be seen in section on the radial face; pitting between ray tracheids and ray-parenchyma cells is half-bordered (Fig. 8, *e*). Ray tracheids are normally confined to the margins of rays, but in some species of *Pinus* ray tracheids may also occur in the middle portions of a ray, and the low rays of the hard pines may consist wholly of ray tracheids.

Wall thickening.—(a) *Spiral thickening* occurs as a characteristic feature in Douglas fir and yew, and is present in some other species of no commercial importance. The spirals are inclined in one direction, but, because of the depth of focus of the micro-

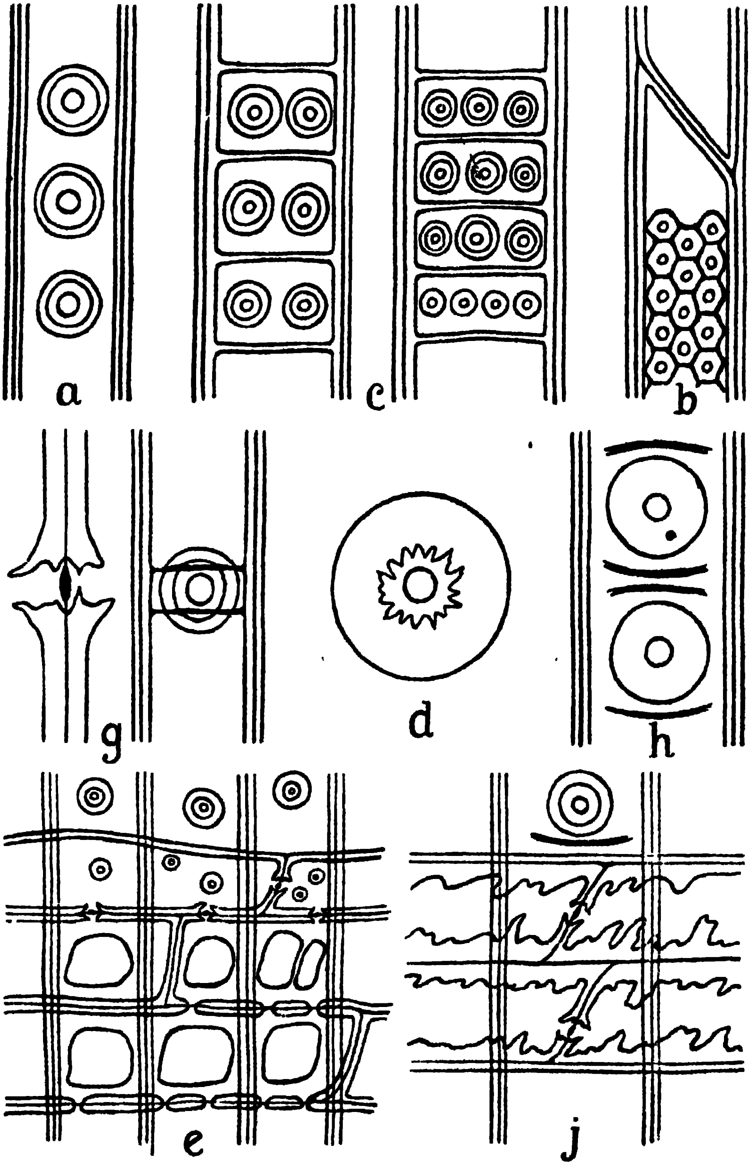


FIG. 8.—Microscopic features used in the identification of softwoods (for explanations see pages 29 and 32 of text)

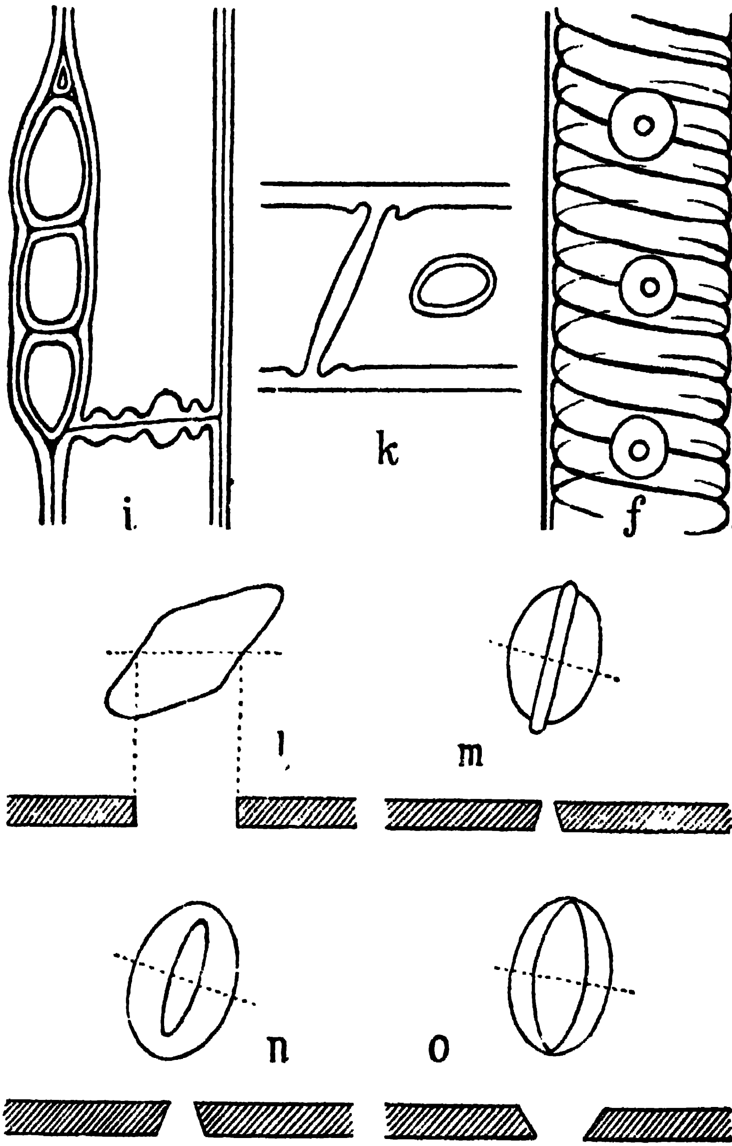


FIG. 8.—Microscopic features used in the identification of softwoods (for explanations see pages 29 and 32 of text)

scope, the spirals in the wall of the cell below may also be seen, producing a reticulate pattern on the wall of the tracheid above (Fig. 8, *f*). In some cases, *e.g.*, *Taxus baccata*, the thickness or depth of the cell exceeds the depth of focus of the objective, and no reticulate pattern is seen. The spirals are actual bands of thickening in the secondary wall. Care must be exercised to distinguish checking in the tracheid walls from spiral thickening.

(b) *Callitroid thickenings*: pairs of thickening bars across the pit border occur in a few species, particularly in the genus *Callitris* (Fig. 8, *g*).

(c) *Crassulae* (formerly "**Bars of Sanio**"): concentrations of intercellular substance, appearing as horizontal bars, occur in the radial walls of all tracheids (except in the *Araucariaceae*) above and below the rows of pits (Fig. 8, *h*).

(d) *Nodular walls*: the transverse or end walls of parenchyma cells of some softwoods are nodular or bead-like in appearance; in a few species the end walls of the ray cells may be similarly thickened (Fig. 8, *i*).

(e) *Dentate thickening*: the lateral walls of ray tracheids of the "hard pines", and, to a lesser degree, in *Picea*, are thickened in an irregular manner, giving the walls the appearance of rows of irregular teeth (Fig. 8, *j*).

(f) *Indentures*: pit-like hollows in the horizontal walls of rays, in which the ends of the vertical walls stand, have been described as **indentures** (Fig. 8, *k*). This feature has been observed in all families of softwoods, except the *Araucariaceae*, but is strongly developed only in some genera.

Cross-field pitting: the area of wall contact between a ray cell and a vertical tracheid is referred to as **a cross field**; the pitting occurring in a cross field takes one or other of five more or less distinct forms. In *Pinus*, the cross field is occupied by one to three large simple, or nearly simple, pits, or one to six small simple, or nearly simple, pits (**pinoid** type) (Fig. 8, *l*). The **piceoid** type refers to early-wood pits with narrow apertures, sometimes extending beyond the margins of the pits (Fig. 8, *m*). In the **cupressoid** type the apertures are included, and rather narrower than the border (Fig. 8, *n*), and in the **taxodioid** type the apertures, which are included, are ovoid to circular, and wider than the border (Fig. 8, *o*). The distinction between the last two types calls for careful observation of sections in proper focus.

CHAPTER III

HARDWOOD TISSUES

TYPES OF CELLS IN HARDWOODS

Whereas in softwoods both conducting and strengthening functions are undertaken by a single type of cell, in hardwoods there is a more distinct division of labour, and the conducting cells, called **vessels** or **pores**, are quite different from the **fibres** that provide mechanical support. The presence of specialized conducting tissue provides a simple means of differentiating hardwoods from softwoods.

The cambial cells of hardwoods are shorter than those of softwoods, and so are the mature cells that arise from the division of these cambial cells. The maximum length rarely exceeds 0·08 in., as compared with 0·4 in. attained by some softwood tracheids. This difference in length, between fibres and tracheids, is one of the reasons why paper-pulp manufactured from hardwoods is almost invariably inferior to that manufactured from softwoods. In hardwoods, as in softwoods, the same cambial cell may give rise successively to conducting, mechanical, or storage cells, or bark tissue; as in softwoods, a special type of cambial cell gives rise only to ray cells.

THE CONDUCTING TISSUE

The counterpart in hardwoods of the thin-walled, conducting tracheids of softwoods are the vessels or pores, illustrated in Fig. 9. This figure shows a vertical series of three fully-developed conducting cells, each of which is known as a **vessel member**. These members are always produced in vertical series, which may extend for a considerable distance in the tree. In Fig. 9 it will be seen that the vessel members have no "end" or transverse walls, but are open top and bottom. When first formed these cells have end walls like other cells, but early in their development

the cells swell and the end walls split and are absorbed, forming rims at either end of each vessel member, so that the members form a continuous tube, like a drain-pipe, in the tree. The individual members are frequently visible on longitudinal surfaces of wood as fine to coarse scratches — the **vessel lines.**

In some species, *e.g.*, birch, alder, American whitewood, the end walls of vessels do not disappear completely; instead, grid-like partitions, **scalariform perforation plates,** are left. The open ends of vessels are called **simple perforation plates.** Scalariform plates are always oblique, and in the radial plane they can be seen with a hand lens on split radial surfaces as in Plate 11, if the vessels are not too small in cross section.

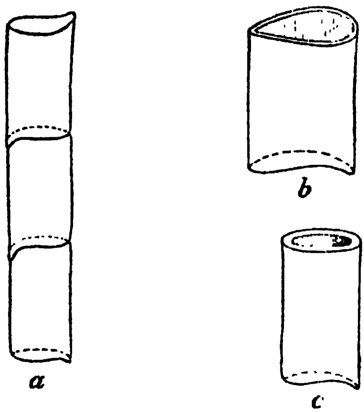


FIG. 9.—Vessel members. *a*, vertical series of three vessel members; *b*, thin-walled early-wood vessel member; *c*, thick-walled late-wood vessel member. (Highly magnified)

It will be clear that the conducting tissue of hardwoods is more effective in providing the water requirements of leaves than are tracheids in softwoods, and this is necessitated by reason of the larger leaf area of broad-leaved species compared with that of conifer needles. Moreover, in addition to the open ends of the vessel members, pits occur in the longitudinal walls, but these pits are smaller than those in the walls of softwood tracheids.

Some hardwoods, of which oak and sweet chestnut are examples, have tracheids in addition to vessels to assist in conduction. These tracheids are similar in appearance to softwood tracheids, but they are shorter, and the pits resemble those of vessel members, and are not restricted to the radial walls.

Vessels are distributed singly, or in radial or tangential groups, or in clusters throughout the wood (Plates 12 and 16, fig. 4). As a general rule, those formed at the beginning of the growing season are wider and thinner-walled than those formed afterwards. In some species the decrease in size is gradual throughout the ring; these are the **diffuse-porous** woods, *e.g.*, beech, birch, poplar, sycamore, and especially tropical hardwoods (Plate 13, fig. 1). In a few species the vessels of the early wood are comparatively large,

PLATE 12

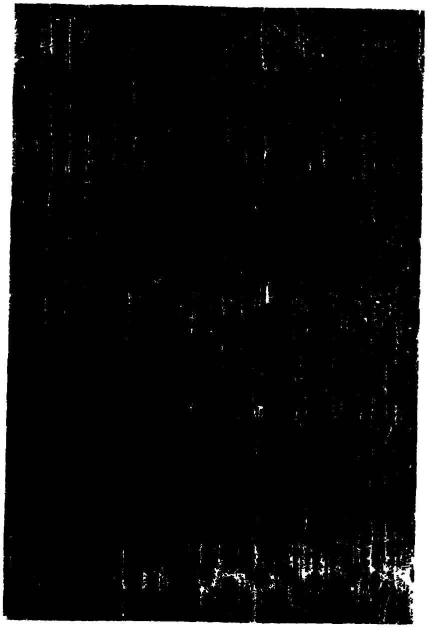


FIG. 1.—Transverse section of Tasmanian oak (mountain ash) (× 10) showing solitary vessels

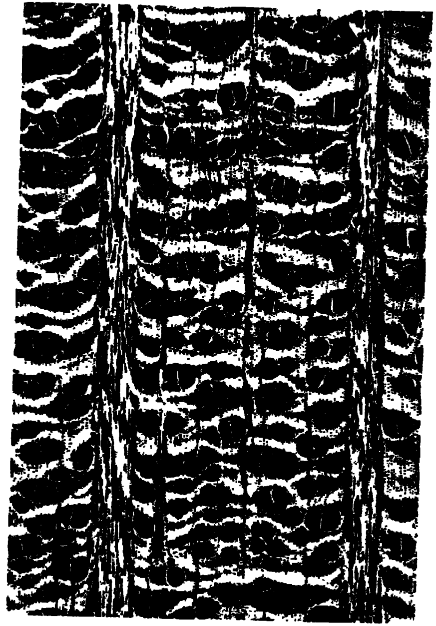


FIG. 2.—Transverse section of Australian silky oak (× 10) showing tangential groups of vessels

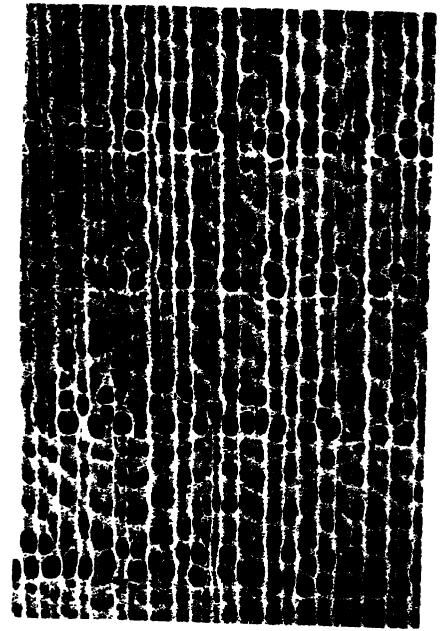


FIG. 3.—Transverse section of wyc elm (× 10) showing clustered a rangement of vessels in late wood

(For radial arrangement of vessels, see makoré, Plate 16, Fig. 6)

Photos by F.P.R.L., Princes Risboroug

PLATE 13

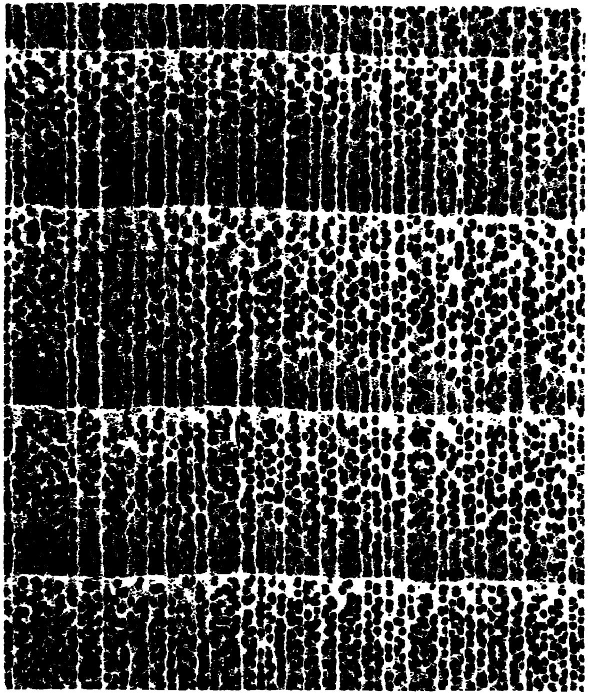


FIG. 1.—Transverse section of a diffuse-porous wood—American whitewood (× 10)

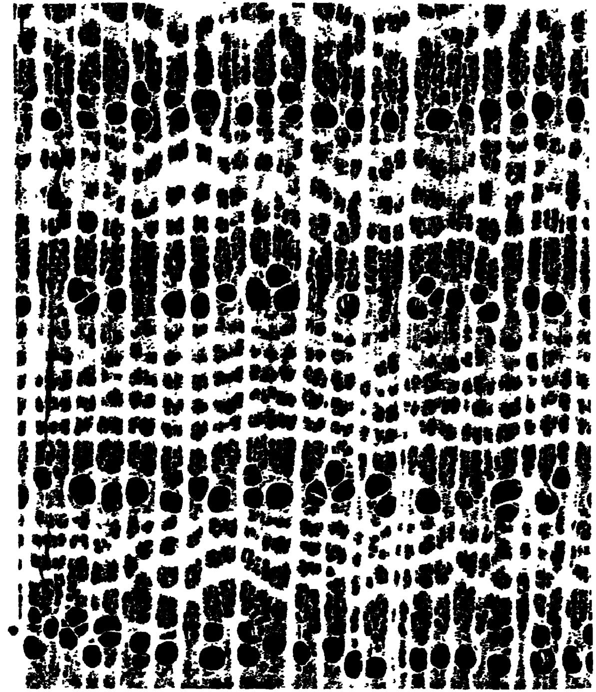


FIG. 2.—Transverse section of a ring-porous wood—elm (× 10)

Photos by L. A. Clinkard

and there is an abrupt change in size to the small and thicker-walled vessels of the late wood; these are the **ring-porous** woods, so called because the early-wood vessels form a distinct ring that can be seen with the naked eye on end surface, *e.g.*, oak, ash, elm (Plate 13, fig. 2).

The vessels of the heartwood do not conduct, but are often blocked with what appear to be foam-like structures, known as **tyloses**, or they may contain solid deposits of a gummy type. Tyloses, as may be seen in Fig. 10 and Plate 14, are ingrowing, bladder-like structures from adjoining ray- or wood-parenchyma cells; on a clean-cut end surface of a piece of wood tyloses appear as foam-like structures in the vessels that often glisten because of differences in light-reflection from the vessel wall and the membranous walls of the tyloses. In bright light the walls of the tyloses produce rainbow effects, similar to those in soap bubbles. When tyloses are themselves filled with gum-like infiltrates, as in meranti, they rarely glisten, and are then liable to be mistaken for solid deposits filling the vessels. All the vessels of the heartwood of some timbers, *e.g.*, robinia (Plate 14), chengal, tembusu, are blocked with tyloses, rendering the line of demarcation between sapwood and heartwood distinct, even in decayed or discoloured wood, where colour differences between sapwood and heartwood are obscured. The formation of tyloses is brought about by differences in pressure between the parenchyma cells and adjacent vessels: when the vessels are actively conducting, the pressures inside the parenchyma cells and vessels are more or less equal, but when the vessels cease to conduct the pressure inside the parenchyma cells is greater than the pressure in the vessels. In consequence, the thin primary wall of the parenchyma pits becomes distended, being blown out like a child's balloon, to fill the vessel cavity.

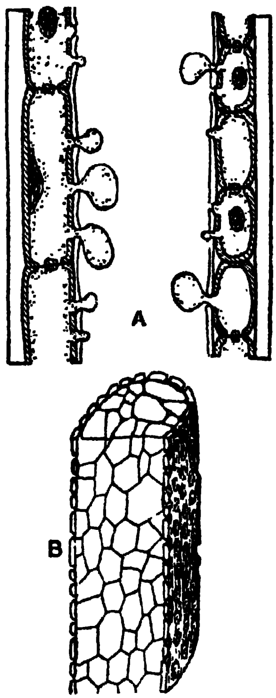


FIG. 10. — Diagrammatic drawing of the development of tyloses: A, stage 1, development from storage cell through the pits into a conducting cell. B stage 2, tyloses completely blocking a vessel

By courtesy of Prof. Forsaith

Tyloses are important from the utilization standpoint: their presence may be beneficial or otherwise. They are beneficial in that they hinder the spread of fungal **hyphae** — the vegetative parts of fungi — that bring about the decay of wood, but tyloses are undesirable in timbers to be treated with wood preservatives, because they impede the absorption of preservatives which, in hardwoods, travel mainly through the vessels and only very sparingly transversely through the pits in the cell walls (in softwoods, where tyloses naturally do not occur, the movement of wood preservatives is largely through the large bordered pits in the tracheid walls).

The presence or absence of tyloses is also a useful character for distinguishing between certain woods. For example, they are absent from the true mahoganies (species of the genus *Swietenia*) and present in meranti (lauan or "Philippine mahogany") (species of *Shorea* and *Pentacme*, family *Dipterocarpaceae*).

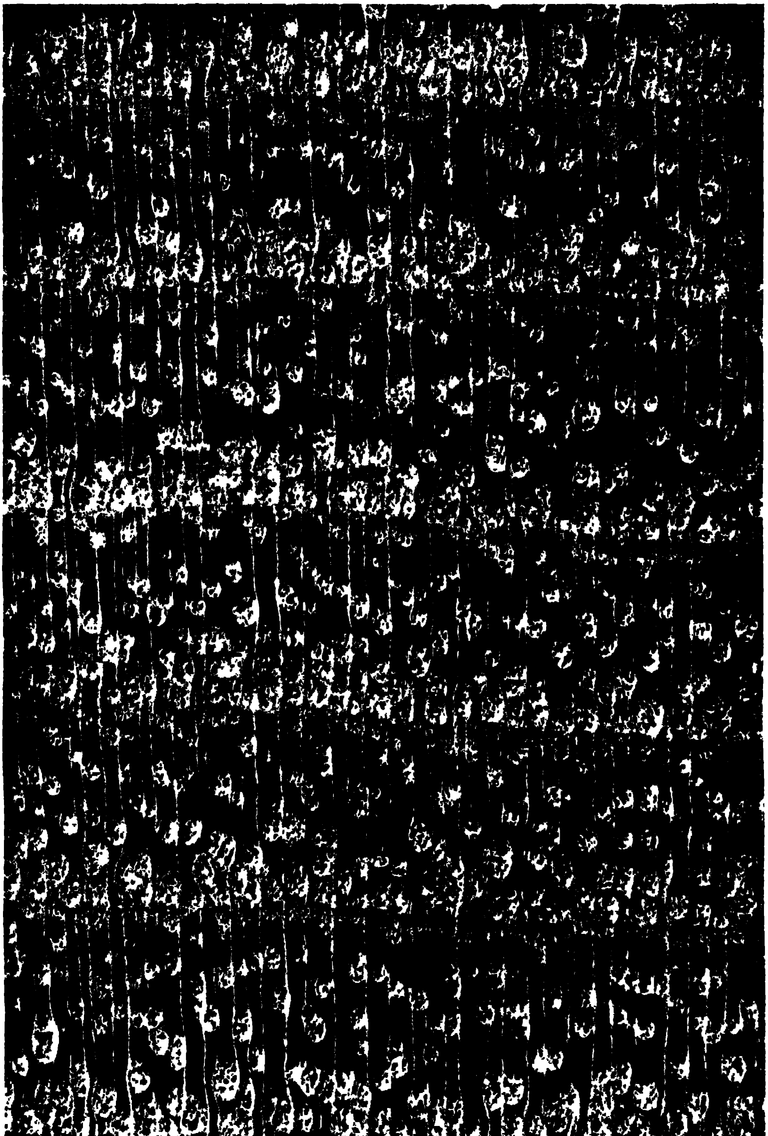
THE STRENGTHENING TISSUE

The mechanical tissue of hardwoods consists of **wood fibres.** These are narrow, spindle-shaped cells, not unlike the late-wood tracheids of softwoods, but they usually have more pointed ends and are shorter. The walls of these cells may be comparatively thin, or so thick that the cell cavity is reduced almost to vanishing point (Plate 15). In discussing the factors that affect the quality of softwoods, the importance of the proportions of thin- to thick-walled tracheids, the thickness of the walls, and the distribution of the different tissues were mentioned. In hardwoods the thickness of the fibre wall and its physico-chemical nature are in many cases the most important factors in determining the strength, shrinkage, and working properties of a timber.

Pits in fibre walls are fewer and smaller compared with those in the walls of other kinds of cells. They are not confined to any particular wall, although they tend to be more numerous in the radial walls.

In some timbers, *e.g.*, teak and gaboon, the cavities of the fibres are divided into small compartments by thin horizontal partitions; such fibres are called **septate fibres.** The reason for the partitioning is not known, but such fibres are more common in species with little parenchyma.

PLATE 14



Heartwood of robinia showing tyloses (× 10)

Photo by F.P.R.L., Princes Risborough

PLATE 15

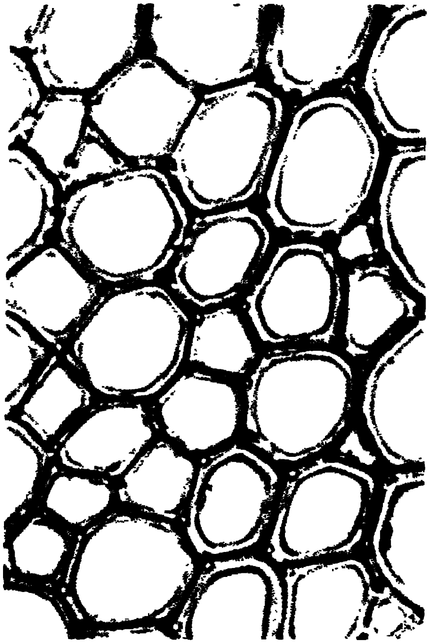


FIG. 1. Transverse section of poplar (× 800) showing thin fibre walls

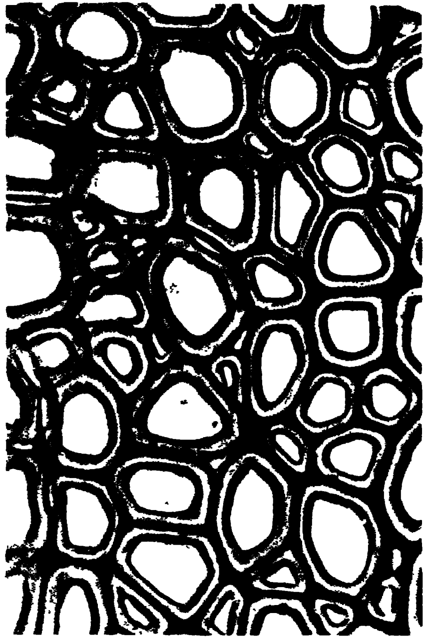


FIG. 2. Transverse section of teak (× 800) showing moderately thick fibre walls

FIG. 3. Transverse section of ekki (× 800) showing thick fibre walls

Photos by L. A. Clinkard

Fibres are sometimes arranged in very regular rows (as seen on cross section); such arrangement is a characteristic and constant feature of several timbers. When the individual fibres are sufficiently large in cross section, their radial arrangement is discernible with the aid of a hand lens (× 10 or × 20 area magnification), *e.g.*, in gaboon.

THE STORAGE TISSUE

In hardwoods the storage tissue is essentially similar to that of softwoods, but it is frequently more abundantly developed, and it displays greater variety in distribution and arrangement. In consequence, wood parenchyma and rays are among the most useful features for distinguishing between different hardwoods.

Wood parenchyma.—Two distinct types of distribution may be differentiated: **apotracheal parenchyma**, which is parenchyma independent of the vessels, and **paratracheal parenchyma**, which is parenchyma associated with the vessels. Both types perform the same function in the tree — that is, they are storage tissue, composed of wood-parenchyma strands. The two types can be further subdivided; apotracheal into **terminal**, **diffuse**, and **metatracheal**, and paratracheal into **vasicentric**, **aliform**, and **confluent.** The foregoing divisions are convenient for purposes of identification, but they are by no means clear-cut. Further subdivisions are possible, which, however, grade into one or other of the divisions enumerated: *vide* Fig. 11. The appearance of the different types of wood parenchyma, as seen on end surface, is described below.

1. *Terminal parenchyma* is the name for the narrow layers of parenchyma cells occurring at the close of a season's growth. If wide enough, the layers are visible to the naked eye as light-coloured lines, marking the boundaries of the rings, as in sycamore (Plate 16, fig. 1). **Initial parenchyma** is used to differentiate "terminal" parenchyma formed at the beginning of the next season's growth instead of at the close of the previous season.

2. *Diffuse parenchyma* consists of single strands distributed irregularly among the fibres, as in pear and box; this type is, as a rule, distinct only under the microscope. When the individual strands are of sufficiently large cross section, they are discernible

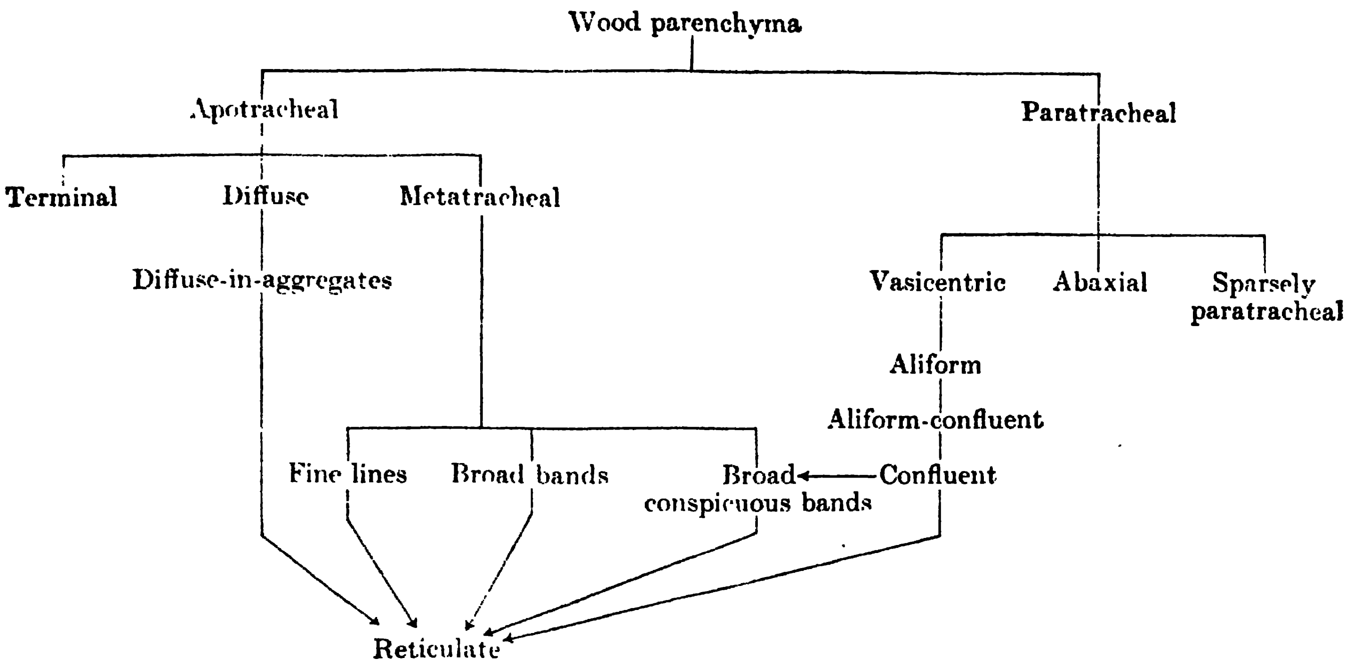


FIG. 11.—Diagram showing different types of parenchyma. The arrows pointing to "reticulate" indicate that the parenchyma may also be reticulate. The arrow between "confluent" and "broad conspicuous bands" is to indicate that the former may not always be easily differentiated from the latter

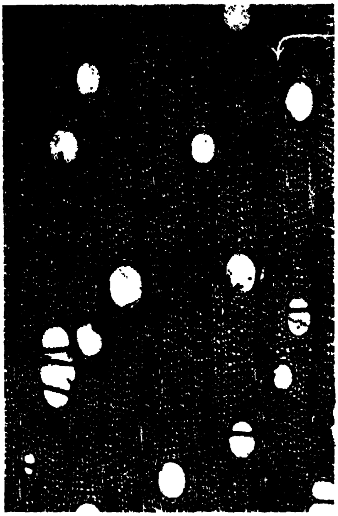


FIG. 3.—Transverse section of obeche (× 15) showing diffuse-in-aggregates parenchyma, *vide* white arrow

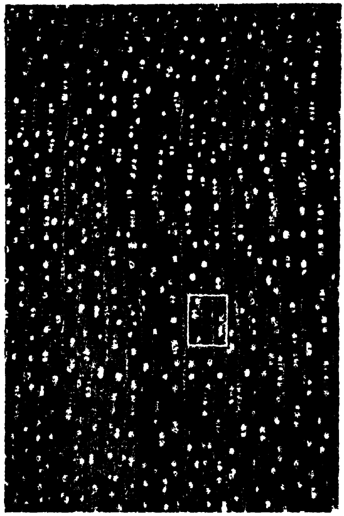


FIG. 4.—Transverse section of *Enantia chlorantha* (× 10) showing fine lines of metatracheal parenchyma, which is also reticulate (see area within white square)

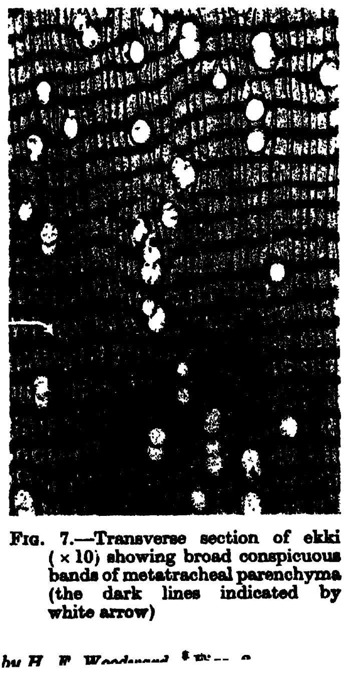


FIG. 7.—Transverse section of ekki (× 10) showing broad conspicuous bands of metatracheal parenchyma (the dark lines indicated by white arrow)

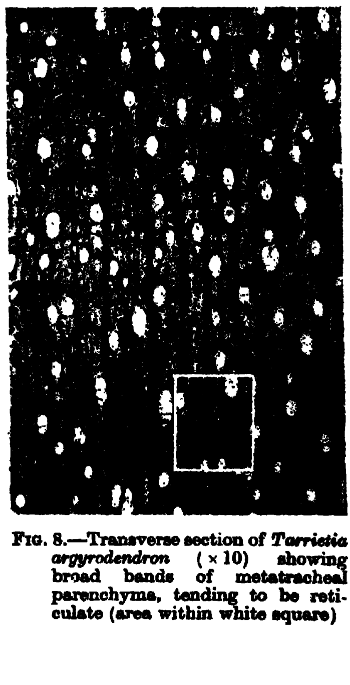


FIG. 8.—Transverse section of *Tarrietia argyrodendron* (× 10) showing broad bands of metatracheal parenchyma, tending to be reticulate (area within white square)

and 8 by H. F. Woodward

with a hand lens as indistinct, light-coloured dots. In woods with numerous parenchyma strands of rather large cross section the end surface may appear characteristically speckled, as in punah.

Diffuse strands tend to aggregate to form fine lines from ray to ray, a condition seen in European walnut, but often only in some parts of the growth ring (Plate 16, fig. 2). In a few woods the fine lines from ray to ray are very regular, and alternate with rows of fibres to produce a very characteristic pattern, as in obeche (Plate 16, fig. 3). The term **diffuse-in-aggregates** has been suggested for diffuse parenchyma forming fine lines from ray to ray.

3. *Metatracheal parenchyma* occurs in tangential layers that are independent of the vessels. These layers appear as lighter-coloured bands, concentric with the growth-ring boundaries. They may be very narrow and only visible with a lens — **fine lines** — as in *Enantia chlorantha* Oliv. (Plate 16, fig. 4), or the layers may be visible to the naked eye — **broad bands** — as in makoré (Plate 16, fig. 6). Fine lines or broad bands differ from the diffuse-in-aggregates type in that they appear to cross several rays, instead of extending only between one pair of rays ; they are often more or less continuous concentric layers. Fine lines or broad bands may be more or less regularly spaced and close together as in ebony and makoré, or widely and irregularly spaced, as in rengas (Plate 16, fig. 5), when they are not readily differentiated from layers of terminal parenchyma. The individual layers vary in width radially ; they may be one to three cells wide, as in makoré, or several cells wide as in ekki (Plate 16, fig. 7), when they are conveniently referred to as **broad conspicuous bands.**

When the layers of parenchyma and the rays are of about the same width, and the distance between the layers is similar to the distance between the rays, a net-like effect is produced on cross section : the parenchyma is then said to be **reticulate** (Plate 16, figs. 4 and 8).

4. *Vasicentric parenchyma.*—Where the tissue is sufficiently abundant to form complete sheaths or borders around the vessels, as in ash, it is said to be vasicentric (Plate 17, fig. 4). In many timbers the borders or sheaths are not complete and therefore the parenchyma is not strictly vasicentric. To meet this objection, the term **sparsely paratracheal** has been proposed for paratracheal parenchyma around the vessels, but not forming a complete sheath (Plate 17, fig. 1). In a few woods the paratracheal parenchyma

is confined to one side of the vessel, the tangential face, as in *Goupia glabra* Aubl. (Plate 17, fig. 2); this type of distribution has been called **abaxial.**

5. *Aliform parenchyma.*—In many timbers the borders extend tangentially in wing-like arrangement, and appear in cross section as diamond- or lozenge-shaped masses containing the vessels, as in merbau. This is aliform parenchyma (Plate 17, fig. 5).

6. *Confluent parenchyma.*—When the tangential projections extend and link up with those of neighbouring vessels, the parenchyma is said to be confluent. Further distinctions in form of confluent parenchyma in different species can conveniently be made. Exceptionally, confluent parenchyma may occur in more or less continuous concentric layers, as in *Millettia* and *Symphoria* (Plate 17, fig. 7), the layers being as broad and as regular as the broad layers of metatracheal parenchyma in ekki (Plate 16, fig. 7). More frequently, the layers of confluent parenchyma are interrupted. In some timbers, where the parenchyma is often no more than vasicentric or aliform at the beginning of a ring, the interrupted layers become more and more continuous outwards in a ring, *e.g.*, Indian rosewood (Plate 17, fig. 6), and other species of *Dalbergia*, and the genus *Pterocarpus*. In other timbers there is no definite distribution of confluent and aliform parenchyma in different parts of the growth ring, the two types intermingling as in iroko (Plate 17, fig. 3), and several timbers of the genus *Terminalia*, typically in afara; Dr. Chalk has adopted the appropriate term *aliform-confluent* for this type of parenchyma. All the foregoing variations in distribution of confluent parenchyma are distinct from the typically aliform type, which inevitably produces short tangential layers where two or more vessels are close together — contrast the short layers towards the end of the bottom growth ring in Plate 17, fig. 5 with the interrupted layers marked with a white arrow in Plate 17, fig. 3; the real nature of the parenchyma in Plate 17, fig. 5 is quite clear over the rest of the cross section illustrated. It will be found useful in identification work to recognize the distinction between aliform, aliform-confluent, and confluent parenchyma as typified in the examples illustrated.

Broad layers of confluent parenchyma are sometimes not easily differentiated with a lens from broad layers of metatracheal parenchyma, when the comprehensive term **conspicuous**

PLATE 18

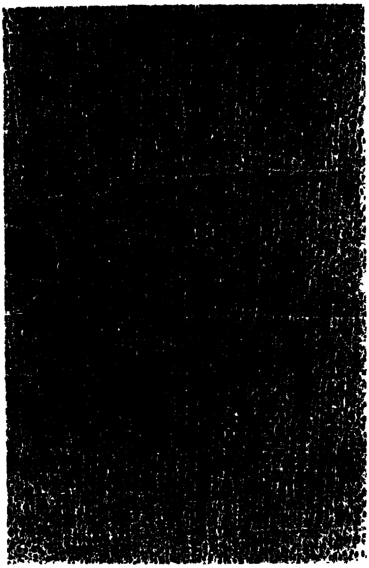


FIG. 1. Transverse section of willow (× 10) showing fine rays

FIG. 2.—Tangential section of willow (× 100) showing uniseriate rays

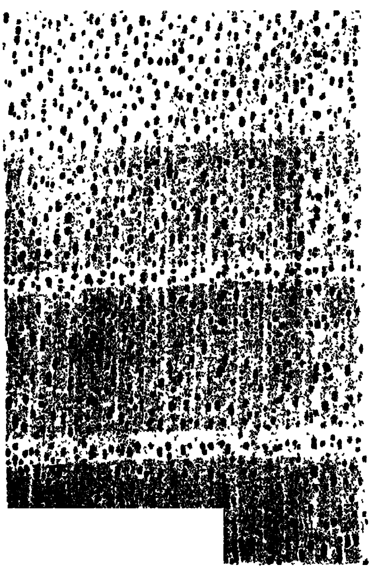


FIG. 3. Transverse section of birch (× 10) showing moderately fine rays

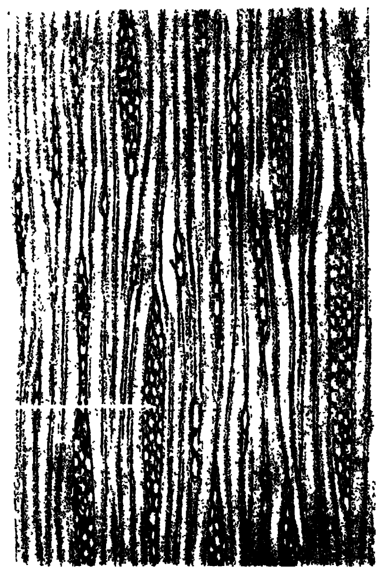


FIG. 4.—Tangential section of birch (× 100) showing the rather small multiseriate rays

Photos by L. A. Clinkard

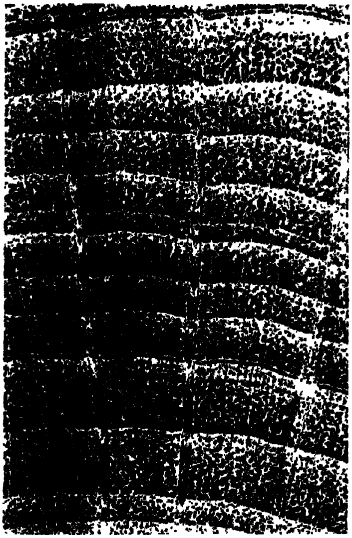


FIG. 1.—Transverse section of beech (× 10) showing broad rays

FIG. 2.—Tangential section of beech (× 75) showing broad, multiseriate

FIG. 3.—Transverse section of oak (× 10) showing rays of two distinct sizes (the fine uniseriate rays are indistinct)

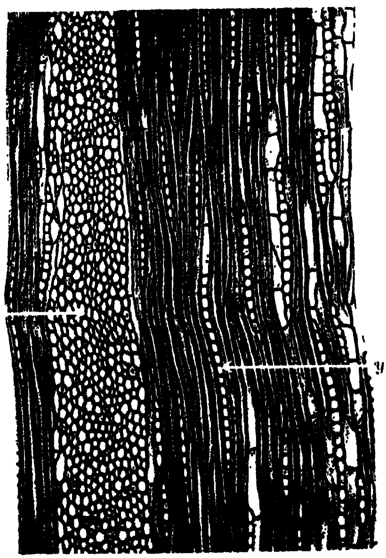


FIG. 4.—Tangential section of oak (× 75) showing a part of a broad ray (*x*) and several uniseriate rays (*y*): note rays of intermediate size do not occur

Photos by L. A. Clinkard

broad bands can be used to embrace both types. With careful examination, it is usually possible to establish whether the broad layers are in fact paratracheal parenchyma or apotracheal parenchyma : if the parenchyma is paratracheal occasional vessels will be observed with parenchyma reduced to the aliform type, whereas reduction in apotracheal parenchyma results in occasional vessels independent of any parenchyma.

The arrangement of the parenchymatous tissue is a useful aid in identifying many timbers : in some timbers only one type is present, but in others two or more types occur. In some, however, the arrangement is too variable to be of any diagnostic value, and other features have to be depended upon for purposes of identification.

Rays.—In softwoods ray tissue is sparsely developed and typically only one cell wide in the tangential direction, *i.e.*, the rays are uniseriate, but in hardwoods there is a considerable variation in both size and number of the rays.[1] Some hardwoods have only uniseriate rays, *e.g.*, poplar and willow (Plate 18, figs. 1 and 2), but in the majority the rays are multiseriate, *i.e.*, more than one cell wide. In some timbers the rays are comparatively uniform in size ; they may be relatively small, and not easily visible to the naked eye, as in birch (Plate 18, figs. 3 and 4), or they may be broad and high, and conspicuous to the naked eye, as in beech (Plate 19, figs. 1 and 2). In other woods rays of two distinct sizes occur : very large rays in association with uniseriate ones, as in oak (Plate 19, figs. 3 and 4). In a few species groups of small rays occur in aggregations that appear to the unaided eye, or at low magnifications,

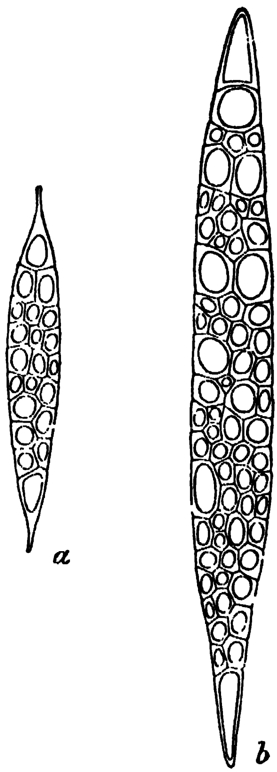


FIG. 12.—*a*, homogeneous ray ; *b*, heterogeneous ray (much enlarged)

[1] In softwoods ray tissue accounts for about 6 per cent. of the total volume of the wood ; in hardwoods the figure is 18 per cent. and upwards.

as single large rays; these are known as **aggregate rays.** The apparently broad rays of hornbeam, hazel, and alder are of this type (Plate 20, figs. 1 and 2).

Very broad rays give rise to the handsome "silver figure"[1] of quarter-sawn timber[2] of the true oaks and Australian silky oak. The presence of broad rays is also an indication that the timbers will split readily in a radial direction, an important property for certain specialized purposes, *e.g.*, the best quality "tight" barrel staves.

Rays are sometimes arranged in regular storeys or tiers that appear on tangential surfaces as wavy, parallel, horizontal lines, known as **ripple marks.** If tangential surfaces of such woods are examined with a hand lens the individual rays are seen: they will be observed as series of storeys or tiers of short vertical lines, the top and bottom ends of each line or ray terminating at the same level as the rays on either side (Plate 20, figs. 3 and 4), and the wavy horizontal lines, visible to the naked eye or hand lens, are the zones without rays that appear lighter in colour; these "lines" are an optical effect, caused by differences in light reflection from the rays and non-ray tissue, and, in consequence, are not seen in sections of wood examined at higher magnifications, *vide* Plate 20, fig. 4. Ripple marks are a useful feature for distinguishing some timbers, *e.g.*, mansonia (Plate 20, figs. 3 and 4) and the true Central American and Cuban mahoganies.

In most timbers with storeyed rays the wood parenchyma tissue, and sometimes the fibres, are also storeyed. In a few, however, the wood parenchyma or fibres, or both, are storeyed but not the rays. In these latter circumstances, although the storeys are visible on both radial and tangential surfaces, it is not possible to determine from the radial surface whether or not the rays are storeyed, and the feature has to be confirmed from the tangential surface. As with storeyed rays, horizontal lines are seen on the tangential surface, but usually much less well defined than with storeyed rays, and the rays cross these lines instead of being bounded by them (Plate 21). Examination of sections under the microscope is necessary to determine which

[1] "Silver figure" is more commonly called "silver grain", but this is a misuse of the term "grain" (see section on Grain, texture, and figure, page 57).

[2] Quarter-sawn is defined on page 57.

PLATE 20

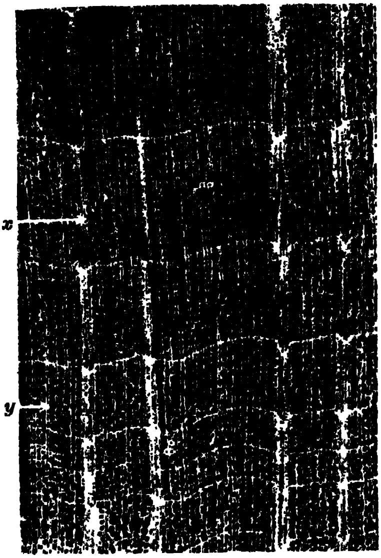


FIG. 1. Transverse section of alder (× 10) showing aggregate rays (*x*) and fine rays (*y*)

FIG. 2. Tangential section of alder (× 50) showing an aggregate ray (*x*) and several uniseriate rays (*y*)

Photos by L. A. Clinkard

FIG. 3.—"Ripple marks" as seen on a tangential section of mansonia (× 35)

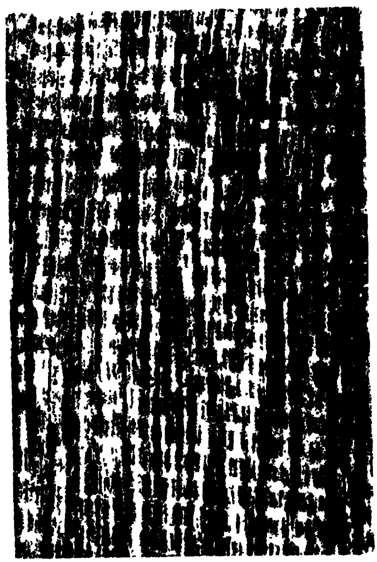


FIG. 4. Ripple marks on a flat-sawn face of mansonia (× 12)

Photos, Fig. 3, by L. A. Clinkard.
Fig. 4, by F.P.R.L., Princes Risborough

PLATE 21

Tangential surface (three times natural size) of *Tarrietia argyrodendron* showing storeyed tissue other than rays.

elements are storeyed. There is no one technical term to describe this feature, which is referred to as "tissue (or elements) other than rays storeyed".

The individual ray cells may be either more or less similar in size and shape (in which case the rays are said to be **homogeneous**, Fig. 12, *a*), or distinctly variable (in which case the rays are **heterogeneous**, Fig. 12, *b*). The example of a heterogeneous ray illustrated is a rather special case, where the size of ray cells varies throughout the ray. More usually, the term is used to define **marginal or sheath cells.** Marginal cells are typically upright cells, of greater height than width, that form margins or tails (according to the viewpoint radially or tangentially). Sheath cells are upright cells enclosing normal ray cells, as seen on tangential surface. A special type of ray cell, called **tile cells**, is common in certain of the *Tiliales* and *Malvales:* these are defined in the "Glossary of terms used in describing woods" (Tropical Woods, No. 36, pp. 1-11) as a "special type of apparently empty upright or square cells of approximately the same height as the procumbent cells and occurring in indeterminate horizontal series usually interspersed among the procumbent cells". The presence of heterogeneous rays and tile cells cannot usually be detected with an ordinary hand lens. The type of ray tissue is a great help in identification, but, without considerable experience in working with a low-power lens, it is not possible in most woods to determine whether the rays are homogeneous or heterogeneous.

CRYSTALS AND DEPOSITS OF SILICA IN WOOD

The storage tissue of many timbers contains crystals, usually of calcium oxalate (Fig. 6, *a* and *b*). These may be confined, in different species, to the wood parenchyma or rays, or they may occur in both tissues. More rarely, these cells contain deposits of silica, *e.g.*, the ray cells of white meranti, Queensland walnut, and apitong (keruing, gurjun, and yang) (Fig. 6, *c*). Crystals and deposits of silica, particularly the latter, may have an important bearing on the working qualities of timbers: an appreciable amount of silica in a wood renders ordinary machine tools and feed speeds uneconomic in the conversion of logs to sawn timber. For example, the standard type of circular saw in use in Malaya for cutting red meranti, when freshly sharpened, will not make

a single cut through a 14 feet long log of *meranti temak*, a form of white meranti with exceptionally high silica content (up to 3 per cent. of the dry weight of the wood). The particles of silica in the sawdust have an abrasive effect on the saw-teeth, producing rapid blunting of cutting edges and heating of the saw. Experiments at Princes Risborough indicate that saws of thicker gauge and wider gullet than normal, and teeth tipped with carborundum, are suitable for the conversion of timbers with high silica content. The presence of silica deposits in wood is of much less importance in the rotary peeling of logs in plywood and match manufacture: this may be explained partly by the logs being peeled after boiling, and partly by the different mechanical effect on the cutting edge of a knife held against a rotating log, compared with the spinning of saw-teeth in an abrasive mixture of sawdust and silica. In the former case, the knife edge tends to push the silica particles to one side, whereas in the latter the silica is ground around the saw-teeth. Timbers containing silica should, whenever practicable, be converted green, as they are then appreciably easier to work. A few timbers without crystals or deposits of silica are equally difficult to saw because of deeply interlocked fibres,[1] *e.g.*, keledang.

RESIN CANALS OR GUM DUCTS

Normal "resin" canals or "gum ducts" are comparatively infrequent in hardwoods, although they are a constant feature of certain families, of which the most important commercially is the *Dipterocarpaceae*, *e.g.*, meranti (lauan), the apitong group, and mersawa. They may occur either as vertical canals in the wood, or horizontally in the rays, or, more rarely, both vertically in the wood and horizontally in the rays, in the same species. The vertical canals may occur in tangential series, producing the appearance of growth-ring boundaries (Plate 22, fig. 1), or they may be distributed in short tangential series throughout the wood (Plate 22, fig. 2) or scattered singly through the wood as in mersawa (*Anisoptera* spp.) (Plate 22, fig. 3), resak (*Vatica* spp.), and agba (*Gossweilerodendron balsamiferum* Harms). The contents of the canals of the *Dipterocarpaceae* usually consist of white or yellow, solid, dammar deposits, but in apitong the deposits are

[1] A definition of interlocked fibres is given on page 59.

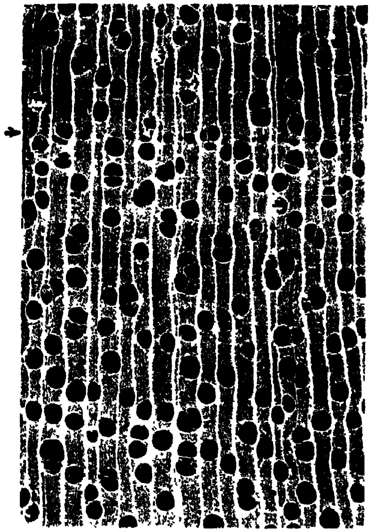


FIG. 1. — Transverse section of meranti (× 10) showing a tangential line of vertical "resin" canals. Note the canals appear black in the figure because the "resin" is dissolved in the process of mounting the section

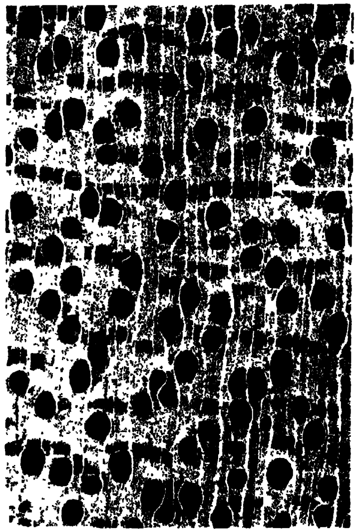


FIG. 2. Transverse section of keruing (× 10) showing the short tangential series of vertical "resin" canals

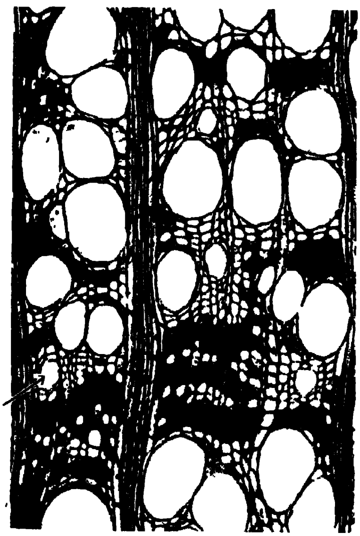


FIG. 3. — Transverse section of mersawa (× 75) showing scattered distribution of the vertical resin canals

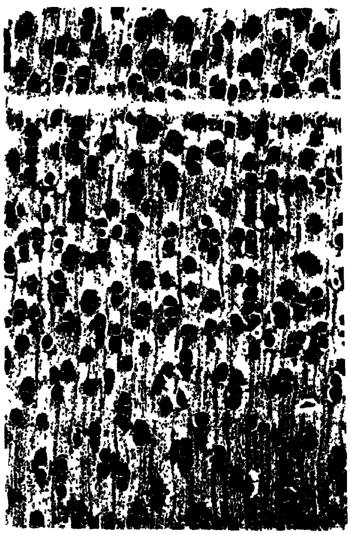


FIG. 4.—Transverse section of African walnut (× 10) showing traumatic "gum ducts"

Photos, Figs. 1, 2 and 4 by L. A. Clinkard. Fig. 3 by F.P.R.L., Princes Risborough

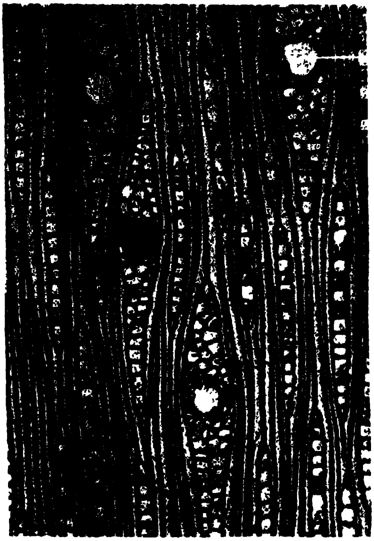


FIG. 1.—Tangential section of rengas (× 75) showing radial canals

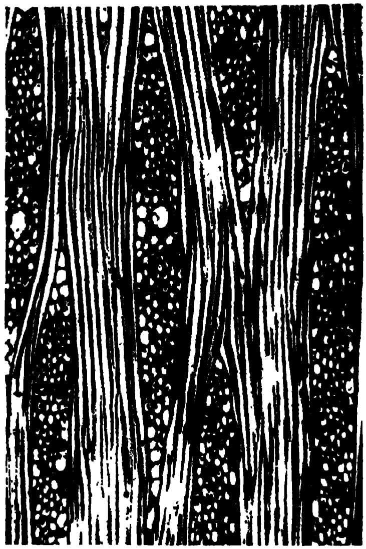


FIG. 2.—Tangential section of *Shorea Faguetiana* showing radial canals (× 75). Compare the small canals with the larger canals in rengas

Photos: Fig. 1 *by L. A. Clinkard* Fig. 2 *by F.P.R.L., Princes Risborough*

FIG. 3.—Transverse section of a vertical resin canal in *Shorea guiso* (× 300)

FIG. 4.—Transverse section of *Strychnos non-blanda* showing islands of included phloem (× 30)

Photos by F.P.R.L., Princes Risborough

viscous oleo-resins, which tend to ooze over sawn surfaces even after the wood is thoroughly seasoned, causing difficulties in painting and other finishing processes. The white deposits, particularly when the canals are in more or less continuous tangential series, are often conspicuous to the naked eye on all surfaces, appearing as prominent white lines, erroneously called "mineral streaks" [1] in the trade.

Radial canals are illustrated in Plate 23, figs. 1 and 2.

Intercellular canals or gum ducts are produced as a result of wounding in many hardwoods. Such canals are said to be traumatic; they may be distinguished from the normal type because they are invariably in tangential series and they usually contain dark-coloured, more or less viscous, gum-like deposits (Plate 22, fig. 4). Further, traumatic canals are usually larger than the vessels, and typically widest tangentially. In some species traumatic canals are sufficiently frequent in occurrence to be regarded almost as a characteristic feature of the timber, *e.g.*, African walnut.

LATEX CANALS

Special cells or tubes, concerned with the storage of latex, occur in the ray tissue of certain timbers. They are usually invisible to the naked eye, but where they can be detected they are a helpful feature in identification. In a few timbers, *e.g.*, jelutong and mujua, specialized parenchymatous tissue, containing numerous latex canals, develops from leaf-traces and continues outwards during the subsequent growth of the bole; such canals, as seen on tangential surfaces, are up to ½ in. high and lens-shaped in section (Plate 24). As the leaf-traces occur in whorls the latex tissue is found in tangential series at intervals of 2 to 3 ft, disfiguring long lengths of timber, and rendering it unsuitable for many purposes. Long splits often develop from the latex passages during seasoning.

INCLUDED PHLOEM

A few timbers contain strands or layers of phloem tissue included in the secondary xylem, as a result of abnormal development of the cambium. This phloem tissue is known as included

[1] A definition of mineral streaks is given on page 201.

phloem. The zones extend up and down the tree, but they may be quite small in cross section (Plate 23, fig. 4), or several inches wide tangentially and up to $\frac{1}{2}$ in. radially (Plate 25). Included phloem, being of different structure from normal wood, may affect the working qualities and seasoning properties of timbers. In some timbers the included phloem is softer than normal wood, and is inclined to pull or tear out when longitudinal surfaces are worked with machine or hand tools, but in other timbers, *e.g.*, kempas (Plate 25), the included phloem consists of harder tissue than normal wood, and behaves differently in seasoning, giving rise to serious splits; this abnormal wood also impedes the penetration of wood preservatives, even when the timber is subjected to "full-cell" pressure processes.

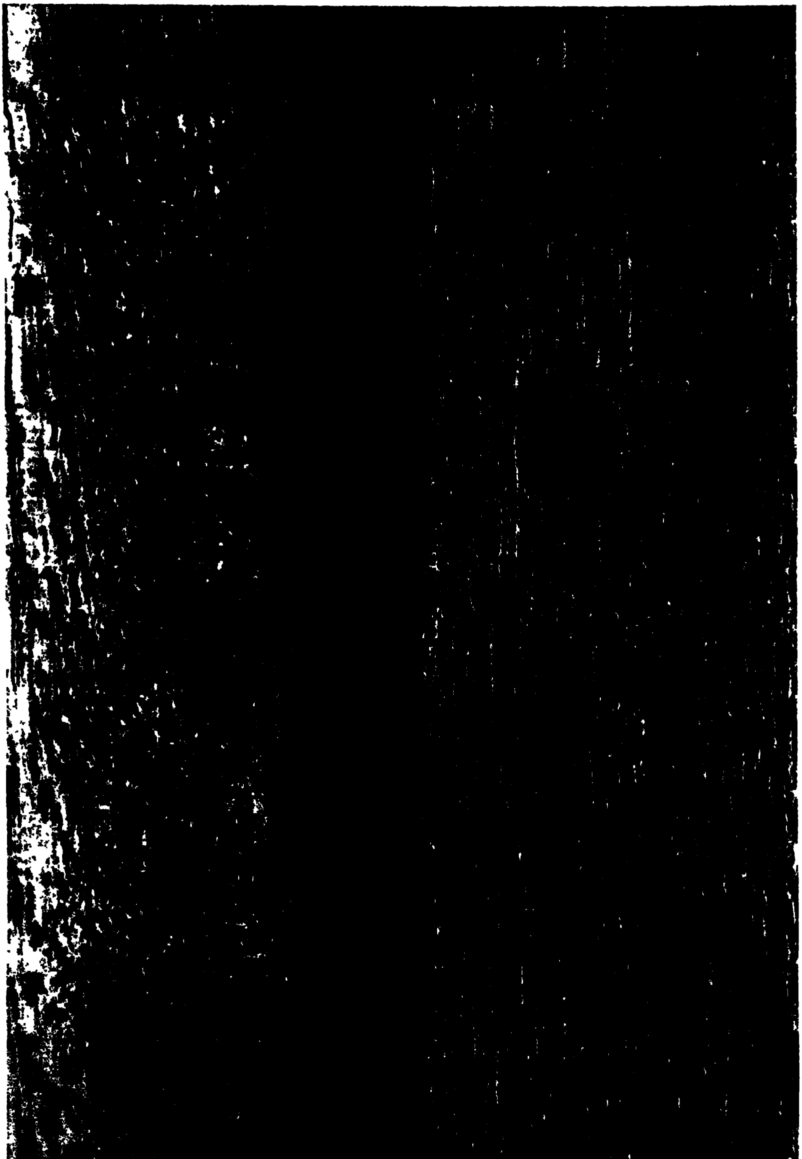
In the foregoing pages the units composing woody structure have been discussed only in the detail necessary for a proper understanding of the properties and identification of wood. Readers who wish to go further into the subject are referred to such works as Eames and MacDaniels's *An introduction to plant anatomy*, and standard text-books on botany.

PLATE 24

Tangential face of mujua board showing a series of ribbons of parenchymatous tissue containing latex canals (natural size)

Photo by F.P.R.L., Princes Risborough

PLATE 25



Quarter-sawn board of kempas with included phloem. Note the splits that have developed in seasoning

Photo by F.R.I., Kepong, Malaya

PART II

THE GROSS FEATURES OF WOOD

CHAPTER IV

GENERAL CHARACTERS

In Part I it has been shown how the structure of wood is the outcome of the requirements of the living tree. It remains to be seen how this structure determines the usefulness of timber to man. It has been stated that the kinds of cells, and their arrangement, chemical composition, and physical structure, determine the properties of wood. These factors also govern the details of the gross features such as colour, sapwood, heartwood, and growth rings, which are readily seen with the naked eye, and enable one to assess the quality of timber.

SAPWOOD AND HEARTWOOD

A striking feature of the majority of woods is the differentiation into sapwood and heartwood. Generally speaking, sapwood is lighter in colour and less durable ; with softwoods, and in the log, the sapwood is wetter than the heartwood.

It is usual to regard sapwood as inferior to heartwood, so that one of our first considerations is to examine how far the specification of timber free from sap is justified. That this is a point of considerable importance will be realized when it is seen how high is the percentage of sapwood in an average log. For example, a 2-in. ring of sapwood is not exceptional, but it represents 56 per cent. of the total volume in a log 12 in. in diameter, 30 per cent. for 24 in. diameter, 21 per cent. for 36 in. diameter, and 16 per cent. for 48 in. diameter. A 1-in. ring in a 12-in. diameter log represents 31 per cent. of sapwood. Some tropical timbers have as much as 12 in. of sapwood in 30- to 36-in. diameter logs. In general, it may be said that average-size commercial logs contain between 25 and 30 per cent. of sapwood, which, if discarded, represents appreciable waste. The properties common to sapwood and heartwood, and those that differ, may be summarized as follows :

Colour.—In some timbers there is no colour distinction between sapwood and heartwood, but in the majority the heartwood is more deeply coloured.

Weight.—There is usually no significant difference between the weight of sound sapwood and sound heartwood of the same moisture content. Exceptions to this statement are timbers with high infiltrate content, *i.e.*, 5 per cent. or more, when the heartwood is appreciably heavier than the sapwood. In green timber the moisture content of the sapwood is usually higher than that of the heartwood, offsetting to some extent weight differences resulting from infiltrates in the heartwood.

Strength properties.—Mechanical tests indicate that sapwood of the same moisture content and density as heartwood, and free of defects, is approximately equivalent in strength properties. The figures for sapwood are a little lower in some cases, but the differences are not of practical significance.

Durability.—Sapwood is rich in plant food material that is attractive to certain wood-rotting fungi and insects. Different timbers vary appreciably in this respect, and fungi and insects are selective in their hosts. For example, *Lyctus* powder-post beetles must have starch but they cannot attack softwoods [1] or small-pored hardwoods because of the lack of facilities for egg-laying. Further, starch in itself is not sufficient to attract powder-post beetles, the presence of traces of other substances appears to be essential to render timbers liable to attack, and these substances are removed by prolonged soaking of timber in water. The infiltrates of the heartwood, on the other hand, are frequently positively toxic to fungi and insects. In positions where wood is exposed to the risk of decay, or to insect attack, sapwood is usually much more readily attacked than heartwood of the same species. Moreover, the presence of large quantities of sapwood, resulting, in favourable circumstances, in vigorous growth of wood-rotting fungi, or heavy infestation of an insect pest, may lead to spread of such attack to adjacent heartwood.

[1] This statement, although generally true, appears to require qualification; the infestation of the sapwood of *Pinus canariensis* C. Sm. by *Lyctus* powder-post beetles has been recorded in South Africa. Infested sapwood of susceptible hardwoods immediately in contact with softwood sapwood may result in the latter becoming attacked by the feeding larvae, but this, of course, is a different matter from infestation originating in such timber.

Special considerations arise when repairs to wood-work are necessitated by decay resulting from fungal activity: in these circumstances it is rarely possible to ensure that all traces of fungal hyphae are eradicated, so that, as a precautionary measure, only timber free from sapwood should be used for the repairs, unless pressure-treated timber is employed to replace the defective wood.

Permeability.—The conducting tissue of wood usually undergoes modifications at the time of heartwood formation so that the free movement of liquids is interrupted. Further, various substances are deposited on the walls of most cells during transition to heartwood, which renders them more or less impermeable to moisture movements. In consequence, heartwood is not so easily impregnated with preservatives or dyes as is sapwood. This may be of less practical importance than is apparent on the surface: heartwood possesses more natural resistance to fungal and insect attack than sapwood, and the reduced absorption of wood preservatives may still be sufficient to ensure that the more lightly treated heartwood will outlast the mechanical life of the treated timber. Where service conditions impose no limits on the growth of fungi, it is not unusual for the heartwood to decay, while the outer, heavily impregnated sapwood remains quite sound.

The case for using or rejecting sapwood.—Where colour is of primary importance it is usually necessary to exclude sapwood, but the difficulty may sometimes be overcome by judicious staining. For some purposes, however, absence of colour is considered desirable, and in these circumstances the light colour of the sapwood is an advantage. Where colour is unimportant, durability may be the controlling factor, and durability depends on the conditions under which the timber is to be used. For outdoor uses generally, *e.g.*, fencing, posts, gates, and railway sleepers, sapwood should be excluded unless the wood is treated with a preservative, in which case it may safely be retained if an adequate treatment is to be given. In well-ventilated, dry, internal situations, such as carcassing and joinery work generally, there is no objection to sapwood (1) if the timber is thoroughly seasoned *before* it is installed, (2) if the site conditions cannot reasonably be expected to alter adversely *after* the timber is installed, and (3) if the timber is not one prone

to powder-post beetle and borer attack, or if the risk of such attack is remote. In effect, in temperate regions the sapwood of softwood timbers can be retained in most indoor situations, but that of several hardwoods, *e.g.*, oak, mahogany, and walnut, should be excluded, as it is susceptible to powder-post beetle attack. In the tropics the risk of wood-borer infestation of several types is so much greater that even the sapwood of timbers immune to powder-post beetle attack should be severely restricted in timber to be used untreated for semi-permanent or permanent work, and its total exclusion from furniture and high-class flooring and joinery is advisable.

Although sapwood may be used in certain circumstances, it must not be overlooked that its presence is a potential source of danger should the site conditions change at any time, and this fact must be borne in mind when drawing up a specification. For example, there is a greater risk that built-in wall plates and ground-floor, basement, and roofing timbers may be exposed to damp than there is that first-floor and ceiling joists will be, and damp conditions render wood liable to fungal attack. It would, therefore, be reasonable to allow sapwood in positions where the risk of attack is small, and to exclude it where the likelihood of infection is considerable. It will often be found impossible in practice to obtain softwood timber entirely free of sap, so that the problem resolves itself into paying proper attention to "site" conditions. Damp-proof courses and air bricks provide the means for maintaining good internal conditions, and it is imperative that they should be given proper attention. It is not unusual, for example, to find ground-line air bricks blocked-up, or for flowerbeds to be raised above the damp-proof course: in such circumstances the protective measures are rendered ineffective. Other causes of damp interiors, likely to lead to decay of timber in a building, are neglected pointing, inadequate or ineffective rainwater disposal arrangements, or plumbing leaks. Stopped-up rainwater heads and gutters, cracked down pipes, and neglect of flashings are probably the commonest causes of "dry rot" in houses, and are of greater significance than the amount of sapwood in the timbers of such houses. Since, however, neglect of maintenance of rainwater disposal arrangements is so prevalent a failing, the increasing use of timber containing large quantities of sapwood tends to make the situation still

worse: temporary neglect provides the opportunity for fungi of the *Merulius* type to become established, and recurring neglect results in serious decay. The extended use of impervious floor coverings, laid tight up to skirtings, in rooms subject to condensation, or where floors are frequently washed, also gives rise to conditions favourable to fungal infection, and the large quantities of sapwood ordinarily used today tend to increase the hazard of decay originating in this way.

As sapwood is more readily impregnated with preservatives than heartwood it should be retained whenever the material is to be properly impregnated, particularly if the timber is in the round, or roughly squared, and is completely encircled by sapwood. If the application of preservatives is confined to brush coating the ends of beams, joists, or posts, sapwood pieces should not, of course, be selected in preference to timber free from sapwood.

In certain other circumstances, *e.g.*, sports goods, tool handles, shuttles, spools, and bobbins, sapwood is sometimes preferred to heartwood, but in most cases there is either no justification for the preference, or the heartwood of the timbers used for such purposes does not differ in colour from the sapwood. For example, there was a preference in America for the sapwood of hickory to the exclusion of the heartwood, but exhaustive tests by the Forest Products Laboratory, Madison, showed that the heartwood was equally suitable for all purposes for which the sapwood was preferred. Again, the favourite timbers for shuttles, spools, and bobbins (persimmon, Turkish cornel, and European box) have little or no heartwood, or the heartwood is the same colour as the sapwood. In one or two tropical timbers the sapwood is distinctly lighter in weight than the heartwood, and for this reason is preferred for tool handles, because the strength properties of the lighter timber are more than adequate for the purpose. Keranji is a case in point: the heartwood of keranji contains a high percentage of infiltrates, which increase the specific gravity of the wood appreciably without increasing the strength properties; this added weight is a disadvantage in an already heavy timber for the purpose. Sapwood is, of course, freer from such defects as knots and shakes, but this advantage is minimized in comparison with the outer heartwood of large-sized trees.

GROWTH RINGS OR LAYERS

The second gross feature to be considered is the presence or absence of growth rings or layers. These, it has been explained, occur in timber grown in regions with distinct seasonal climates, in which a growing period alternates with a resting state, and where the wood laid down at one period of the growing season differs from that produced later in the season. The character of the growth ring is sometimes useful in identifying a timber, and is often of value in assessing the quality of a piece of wood.

The width of rings, or the number of rings per inch of radius, is a measure of the rapidity of growth, and is some indication of the strength properties of wood. In softwoods, and the ring-porous hardwoods, variations in ring width are associated with variations in the proportion of late to early wood (Plates 26 and 27). In the diffuse-porous woods, in which the wood produced in a single growing season is not differentiated into early and late wood, variations in ring width are associated with variations in porosity. In all three types of wood extremely narrow and extremely broad rings are an indication of exceptionally weak timber; probably in all species there is an optimum rate of growth for the production of the strongest timber, but the rate differs with the species. In softwoods this optimum is about 7 to 20 rings per inch, and within these limits the *narrower* the ring the *narrower* is the layer of early wood, and, consequently, the *higher* is the proportion of late wood. In ring-porous woods the optimum is roughly 6 to 10 rings per inch, and within these limits the *wider* the ring the *wider* the layer of late wood, and, consequently, the *higher* is the proportion of late wood. These limits are too strict for most practical purposes: work on ash at the Forest Products Research Laboratory, Princes Risborough, has shown that wood within a range as wide as 4 and 14 rings to the inch is likely to be stronger than that of faster or slower growth. It may be recalled that the late wood is composed largely of strengthening material and, therefore, the higher the proportion of late wood the stronger the timber. It follows that within the optimum limits for the species, the narrower the rings of softwoods and the wider the rings of ring-porous hardwoods the stronger the timber.

The weakness of the very slowly grown softwoods and ring-

PLATE 26

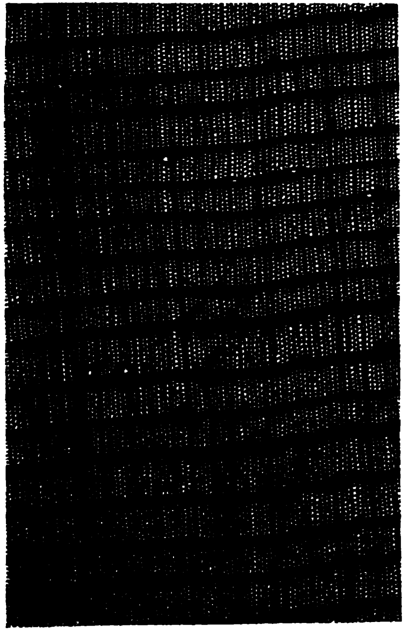


FIG. 1. Transverse section of Douglas fir (× 12). Slow grown (54 rings per inch)

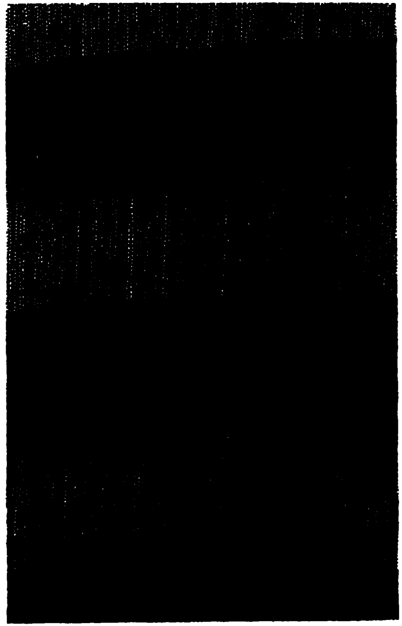


FIG. 2.—Transverse section of Douglas fir (× 12). Medium-slow grown (8 rings per inch)

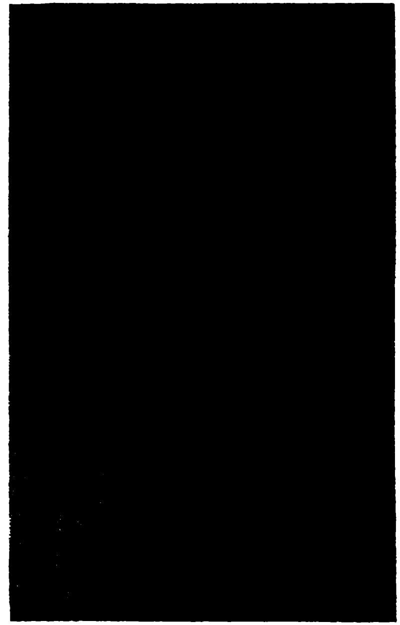


FIG. 3.—Transverse section of Douglas fir (× 12). Fast grown (under 3 rings per inch)

Photos by L. A. Clinkard

PLATE 27

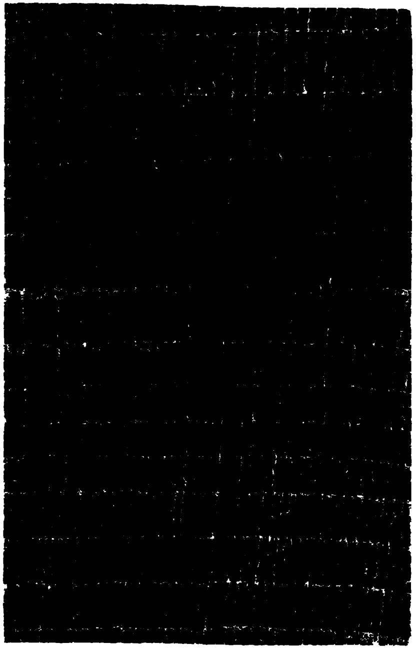


FIG. 1.—Transverse section of ash (× 7). Slow grown (40 rings per inch)

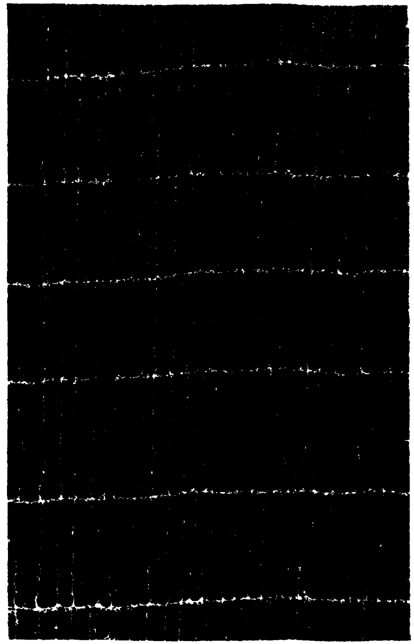


FIG. 2.—Transverse section of ash (× 7). Medium-slow grown (19 rings per inch)

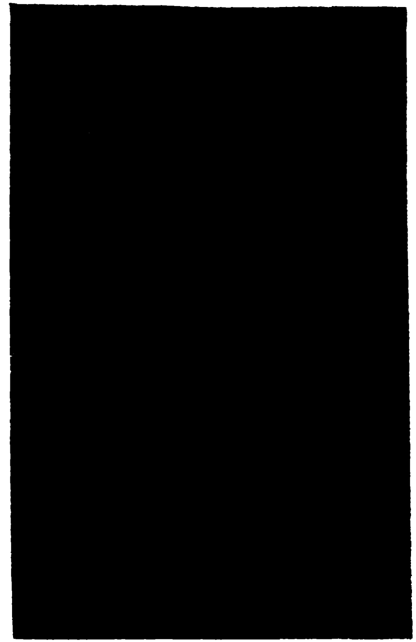


FIG. 3.—Transverse section of ash (× 7). Fast grown (9 rings per inch)

Photos by L. A. Clinkard

porous hardwoods is explained by the very narrow layers of late wood that their rings contain. The weakness of rapidly grown softwoods, on the other hand, is explained by the very wide layers of early wood. In hardwoods grown faster than the optimum limits, however, although there is an increase in the proportion of late wood, the individual fibres are abnormally thin walled, and the timber is, in consequence, weaker than less rapidly grown material in which the late-wood fibres have thicker walls.

Other factors than ring width are more important in determining strength properties of individual pieces of wood, but ring width is a useful rough guide, so long as its limitations are recognized, and it can be used in the timber yard or workshop. For example, the writer classified a stock of ash tool handles into grades on a ring-width basis and, by imposing an arbitrary maximum number of rings per inch of radius, eliminated practically all the inferior timber. On the other hand, mechanical tests showed that the arbitrary classification excluded a considerable proportion of good timber. Had density been utilized as a second factor a more accurate estimate of quality would have been realized. The value of the rings-per-inch classification depends on whether, in practice, the acceptance of a certain amount of inferior timber would be more economical than paying the higher price resulting from the imposition of a stricter specification, and this is a point that must be settled separately for each case.

No specification covering supplies of timber on a commercial scale should rest on a ring-width classification alone: a more important factor is the percentage of late wood. An average of 50 per cent. of late wood is recommended, for example, with some pines for exacting constructional purposes. Other factors, to be later discussed, *e.g.*, density, irregular grain, and defects, also require to be taken into consideration.

Strength properties are not the only factors that determine the merits of a timber: for some purposes working qualities are of equal or greater importance. In such circumstances, timber produced under other than the optimum growth conditions for strength may be superior to that produced under the optimum conditions. For example, mildness in working is associated with narrow-ringed material. The mildest softwood timber is that from northern Europe and the higher altitudes of central Europe, and the rings frequently exceed 20 to the inch; such timber is

unsurpassed for joinery purposes. In the same way, the milder, slower-grown, and consequently narrower-ringed "Austrian" oak is preferred for flooring, panelling, etc., to the faster grown, wider-ringed, and stronger English oak. The English oak is, however, better for constructional work.

COMPRESSION WOOD

In softwoods a special type of tissue, known as **compression wood**, is developed on the under (compression) side of branches and the lower sides of leaning stems. The outstanding feature of this type of wood is its abnormally high longitudinal shrinkage. Whereas normal wood shrinks 0·1 to 0·2 per cent. in drying from the green to the oven-dry condition, compression wood may shrink as much as 5·78 per cent., and is commonly 0·3 to 1·0 per cent.[1] In consequence, boards and planks containing compression wood are liable to bow in seasoning. The abnormal wood is exceptionally dense, but the extra weight is not accompanied by proportional increase in strength; in particular, compression wood has relatively low bending strength and lacks toughness. The changed properties may be attributed to abnormally high lignin content, and for this reason compression wood is not suitable for chemical paper-pulp, and its lack of toughness is equally objectionable in mechanical pulp.

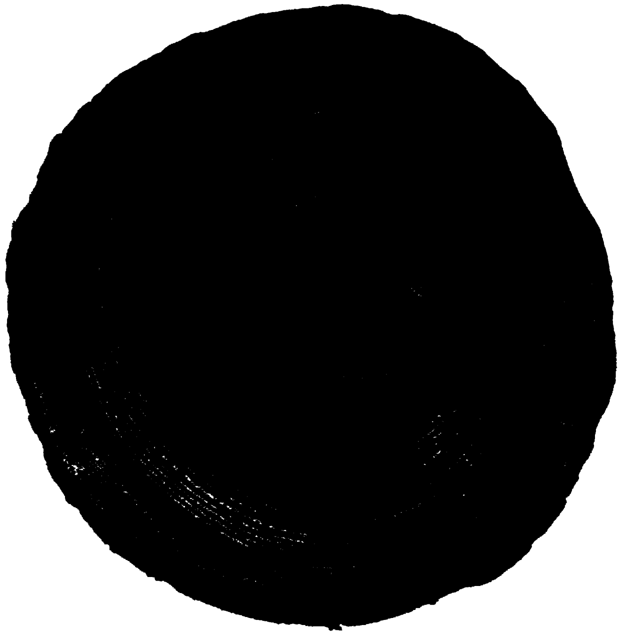
In most species compression wood may be recognized by its relatively dark red-brown colour, and by the lack of contrast in colour between the early and late wood (Plate 28, fig. 1). In boards and planks the abnormal wood frequently occurs in streaks running the length of the timber.

TENSION WOOD

In hardwoods a special type of tissue, known as **tension wood**, is formed on the upper sides of branches and the upper sides of leaning stems (Plate 28, fig. 2). In effect, hardwoods produce tension wood in circumstances where softwoods produce compression wood. Tension wood is paler than normal wood, and it appears more lustrous when viewed by obliquely reflected light.

[1] Figures from "The longitudinal shrinkage of wood", by A. Koehler, in *Trans. Am. Soc. Mech. Engineers*, Jan.–April 1931, vol. 53, No. 5.

PLATE 28



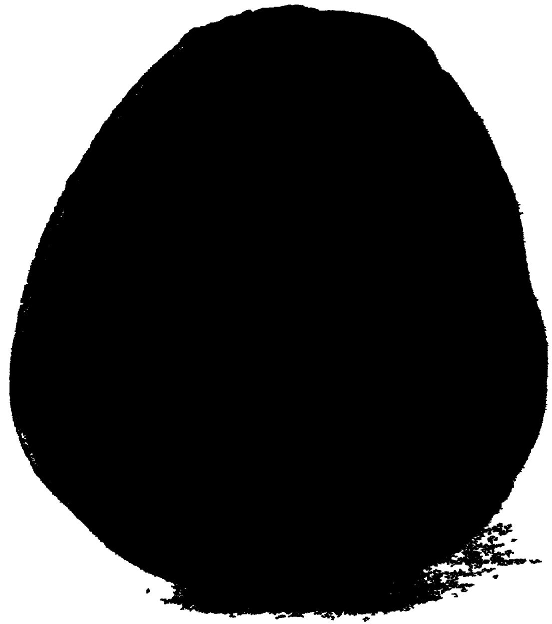


Fig. 1—Cross section of spruce log showing compression wood (the dark, wide ringed portion shown in the lower part of the section)

Photo by U S Forest Products Laboratory

Fig 2—Cross section of beech log showing tension wood

Photo by F P R I, Princes Risborough

Note. tension wood is formed on the upper side of branches and on the up hill side of leaning trees, and compression wood on the lower side of branches and the downhill side of leaning trees

PLATE 29

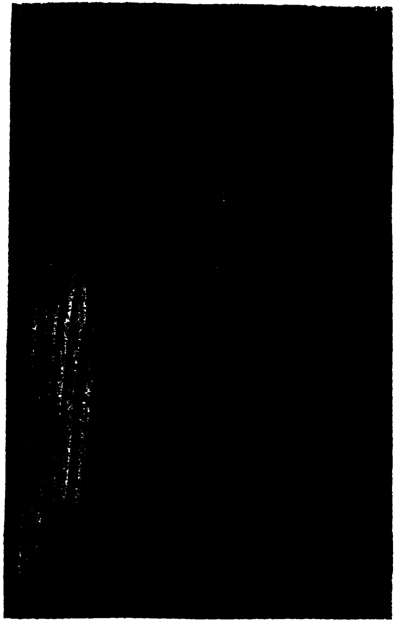


FIG. 1.—Flat-sawn European redwood

By courtesy of E. H. B. Boulton, Esq.

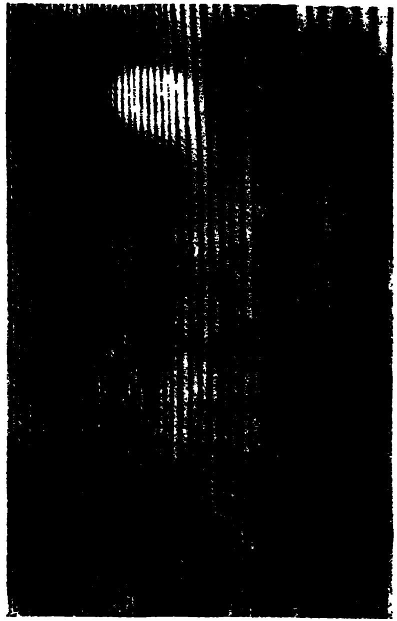


FIG. 2.—Quarter-sawn Douglas fir
(" edge grain ")

By courtesy of the Editor of " Wood "

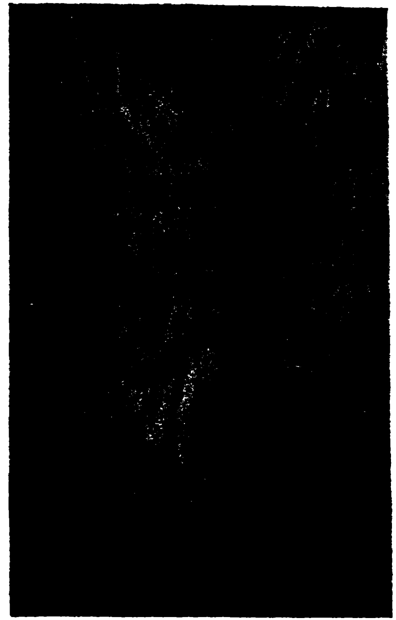


FIG. 3.—Rotary-cut veneer of Douglas fir

Photo by F.P.R.L., Princes Risborough: sample lent by the Editor of " Wood "

It differs from normal wood of equal density in being exceptionally weak in compression parallel to the grain. It is, however, slightly stronger in tension and toughness than normal wood of the same density. As with compression wood, tension wood has abnormally high longitudinal shrinkage; the radial shrinkage is normal, and tangential shrinkage rather greater than normal. Gelatinous fibres are characteristic of the tension wood of many species, *e.g.*, of beech and walnut but not of others, *e.g.*, ash. In all so far examined, the lignin content of the cell walls is deficient compared with normal wood. S. H. Clarke has summarized the working qualities of tension wood as follows: "in the lathe, turnings came from tension-wood cylinders in long, pliable pieces, but those from normal wood were more brittle and broke into small chips. When surfaced on a rotary planer the tension wood was inclined to be woolly where the cutting went against the grain."

GRAIN, TEXTURE, AND FIGURE

Grain and texture should be used to refer to two quite distinct characters of wood, but more often than not they are confused in everyday use. An attempt has been made by timber research laboratories to standardize the use of the terms, restricting each to a single feature. It is proposed that grain shall refer to the direction of the fibres, relative to the axis of the tree or the longitudinal edges of individual pieces of timber, and that **texture** shall apply to the relative size, and the amount of variation in size, of the cells.

Figure refers to the pattern produced on longitudinal surfaces of wood, as a result of the arrangement of the different tissues, and the nature of the grain.

Before describing the different types of grain, it will be as well to discuss the incorrect uses of this term. These fall under several heads, *e.g.*, those describing the manner of sawing, those correctly pertaining to texture, and those referring to width of growth rings. Of the first, we have quarter, edge, vertical, and comb grain, referring to timber that is cut parallel to the rays; for such timber the term "quarter- (or rift-) sawn" is proposed. Timber cut at right angles to the rays should be described as flat- (back-) sawn [1] and not as "flat grain". In hardwoods "coarse" and "fine grain"

[1] Flat-sawn is often referred to as through-and-through sawing.

are frequently applied to characteristics that depend on the size of the elements, and, therefore, are more correctly described as **texture**; oak, for example, should be described as coarse textured and not coarse grained. In softwoods, on the other hand, coarse and fine grained are often used to describe the width of growth rings; the former to wood with broad rings, and the latter to wood with narrow rings. Here the feature is neither grain nor texture, and is better described by the terms **wide- and narrow-ringed** or fast- and slow-grown.

"Even" and "uneven grain" have been used to distinguish regularity and irregularity in the width of growth rings. As this character is neither dependent on the direction of the fibres nor on the size of cells, but on the rate of growth, it is inaccurate to refer to it as either grain or texture, and a much clearer idea is given by employing the phrase "**growth rings regular** (or **irregular**) **in width**".

Timber that breaks with a short, brittle fracture is frequently described as *short in the grain*. The description is inapt, as the failure has nothing to do with the length of the fibres, nor is it connected with their direction, in relation to the vertical axis of the tree, but with their brittleness, *i.e.*, the readiness with which the fibre walls fracture at right angles to their length. Brittleness may be an inherent property of the species, or it may be caused by such factors as fungal decay, "spongy heart"; exceptionally low density (for the species), compression wood, or even maltreatment in seasoning (usually too rapid drying in a kiln at a high temperature and too low humidity). Tropical timbers tend to be more brittle than temperate-climate woods of similar density because of their higher lignin content. Brittle timbers, however, are stiffer than more flexible ones, and for some purposes this may be an advantage, provided they are not likely to be overloaded, when they would fail suddenly and without warning.

"Grain" is sometimes applied to describe the figure of a timber: *silver grain*, for example, refers to the appearance of timbers with broad rays, cut on the quarter; it is only indirectly connected with the direction of the cells, *i.e.*, the broad plates of ray tissue such as occur in the true oaks and Australian silky oak; to be consistent, figure arising from the presence of broad rays should be described as **silver figure** (Plate 30, fig. 1).

Grain.—Using the restricted meaning, six types of grain may

PLATE 30

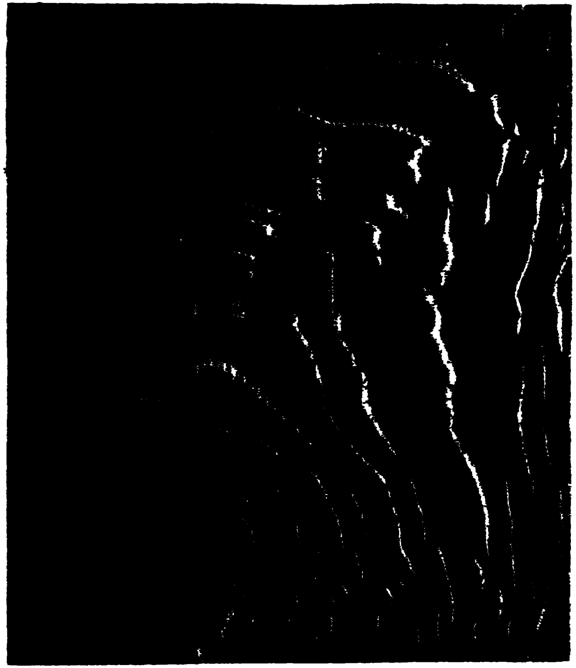


FIG. 1. —Silver figure in quarter sawn oak

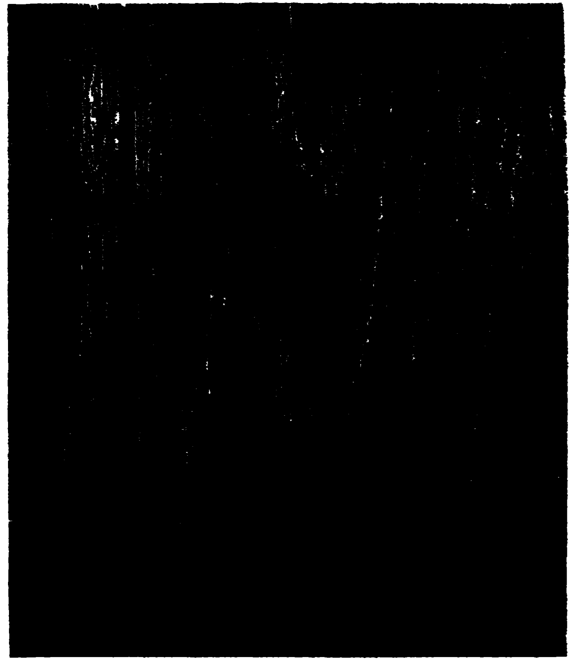


FIG. 2 —Flat-sawn oak

Photos by F P.R L, Princes Risborough

PLATE 31

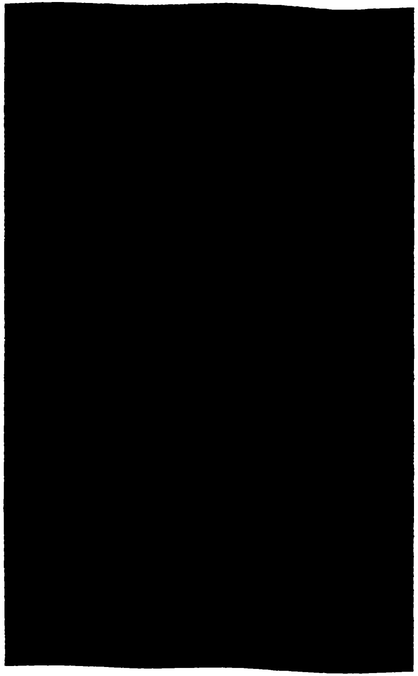


Fig. 1.—Blister figure in Pacific maple

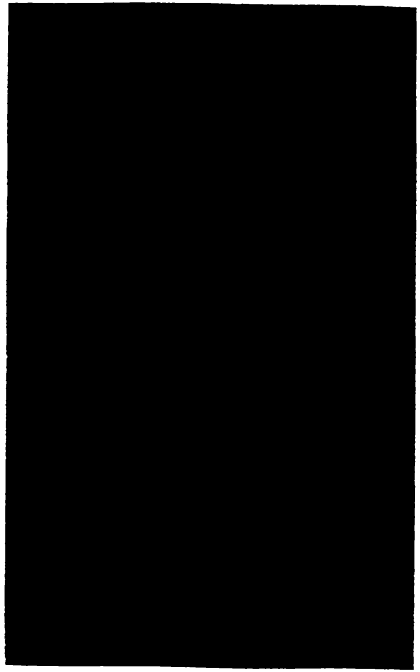


Fig. 2.—Bird's-eye figure in maple

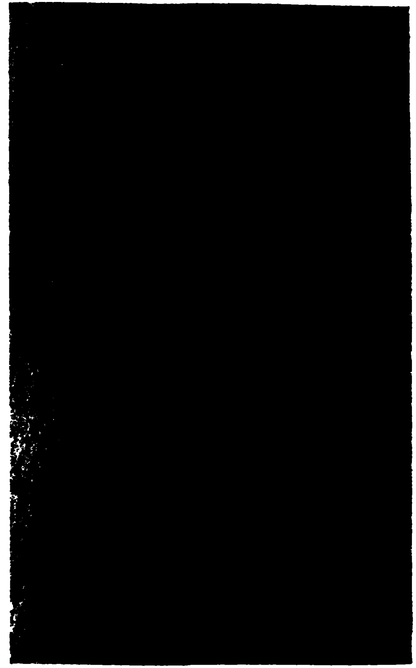


Fig. 3.—Curl figure in Spanish mahogany

Photos by F.P.R.L., Princes Risborough : veneers lent by Messrs. John Wright (Veneers) & Sons

be distinguished. Straight grain explains itself. In straight-grained timber the fibres and other elements are more or less parallel to the vertical axis of the tree. In addition to being a contributory factor in strength, straight-grained timber makes for ease of milling and reduces waste. On the other hand, it does not give rise to ornamental figure.

Irregular grain.—Timber in which the fibres are at varying, and irregular, inclinations to the vertical axis in the log, is said to have irregular grain. It is frequently restricted to limited areas in the region of knots or swollen butts. It is a very common defect and, when excessive, seriously reduces strength, besides accentuating difficulties in milling. Irregular grain, however, often gives rise to an attractive figure. Pronounced irregularities in the direction of the fibres, resulting from knoll-like elevations in the annual rings, produce blister figure (Plate 31, fig. 1). The valuable and attractive bird's-eye figure (resulting from conical depressions as opposed to the elevations in blister figure) seen on the finished tangential surfaces of selected material of a few species, *e.g.*, maple, is held to be the result of temporary injury to the cambium (Plate 31, fig. 2).

Diagonal grain is a milling defect, and results from otherwise straight-grained timber being cut so that the fibres do not run parallel with the axis of the board or plank; such timber is weaker than that properly sawn.

Spiral grain is produced when the fibres follow a spiral course in the living tree. The twist may be left- or right-handed. The inclination of the fibres may vary at different heights in the trunk, and at any one height the inclination may vary at different distances from the pith. The cause of spiral grain is not definitely known, but there is evidence that it is an hereditary characteristic of individual trees. Although not always readily visible, spiral grain may often be detected from the direction of the surface seasoning checks, often visible for example on telegraph poles. Spiral grain reduces the strength of timber and is, therefore, a serious defect in timber for important structural work.

Interlocked grain, or interlocked fibre as it is often called, results from the fibres of successive growth layers being inclined in opposite directions, producing on quarter-sawn surfaces the familiar figure known as ribbon or stripe figure (Plate 32, fig. 1). Interlocked grain is relatively uncommon in temperate woods but

it is a characteristic feature of most tropical timbers. As far as is known, it does not appreciably affect the strength of timber, but it may cause serious twisting during seasoning and, if pronounced, makes the wood difficult to split radially (Plate 33, fig. 2). There is also the added disadvantage that such timber "picks up", particularly when being planed on the quarter, leaving a very rough finish. In timbers with heavily interlocked grain, *i.e.*, when the pitch (the angle between the fibres and the vertical axis of the tree) exceeds 20° or 30°, and the successive changes in inclination of the fibres occur at intervals of $\frac{1}{4}$ to $\frac{1}{2}$ inch radially, sawing difficulties may be very great: the fibres tend to pull out and wrap themselves round the saw-teeth until the saw becomes buried in the log, bringing all machines driven off one motor or engine to a standstill. With timbers in this class, *e.g.*, keledang, sepul, and terentang, interlocked grain can cause as much trouble in conversion as does the high silica content of other timbers. A reasonably smooth surface can, however, be obtained in sawing and planing with modern machines, employing more set than is ordinarily required, a suitable cutting angle, and a modified rate of feed.

Wavy grain.—When the direction of the fibres is constantly changing, so that a line drawn parallel with them appears as a wavy line on a longitudinal surface, the grain is said to be wavy. This type of grain gives rise to a series of diagonal, or more or less horizontal, darker or lighter stripes on longitudinal surfaces, because of variations in the reflection of light from the surface of the fibres: this is called **fiddle-back figure** (Plate 32, fig. 3). Wood with wavy grain presents a corrugated surface, as shown in Plate 33, fig. 1, when split. The importance of this type of grain lies in its decorative value, and any reductions in strength are of no consequence. Wavy grain may occur, together with interlocked grain, in one piece of timber, giving rise to a broken "ripple" on quarter-sawn surfaces, called **roe figure** (Plate 32, fig. 1).

Texture.—Just as it was necessary to employ qualifying adjectives to describe the different types of grain, so is it with texture, and we have the terms coarse, fine, even, and uneven texture. The differentiation between coarse and fine texture is made on the dimensions of the vessels, and the width and abundance of the rays. Timbers in which the vessels are large, or the

PLATE 32

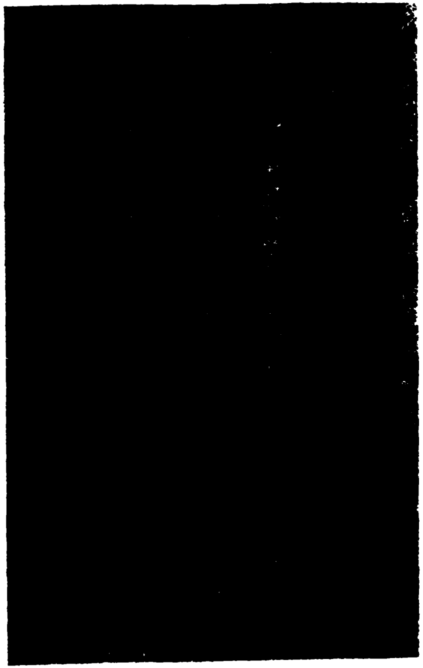


FIG. 1.—Stripe or ribbon figure in African mahogany

By courtesy of E. H. B. Boulton, Esq.

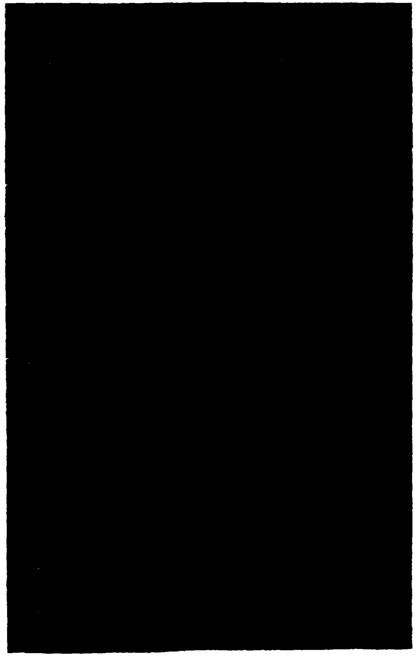


FIG. 2.—Roe figure in mahogany

Photo by F.P.R.L., Princes Risborough ; veneer lent by Messrs. John Wright (Veneers) & Sons

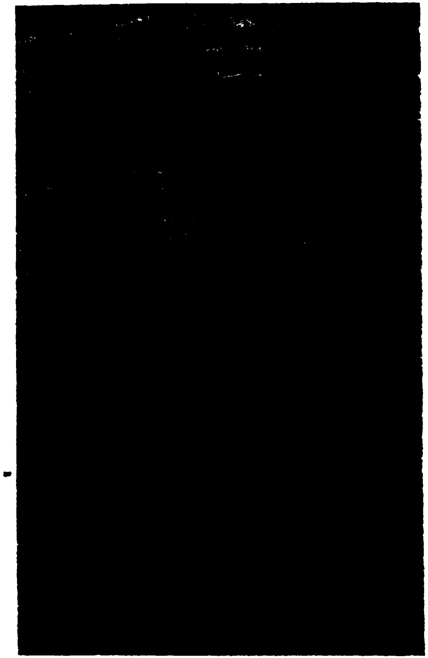


FIG. 3.—Fiddle-back figure in walnut

Photo by F.P.R.L., Princes Risborough ; veneer lent by Messrs. John Wright (Veneers) & Sons

PLATE 33

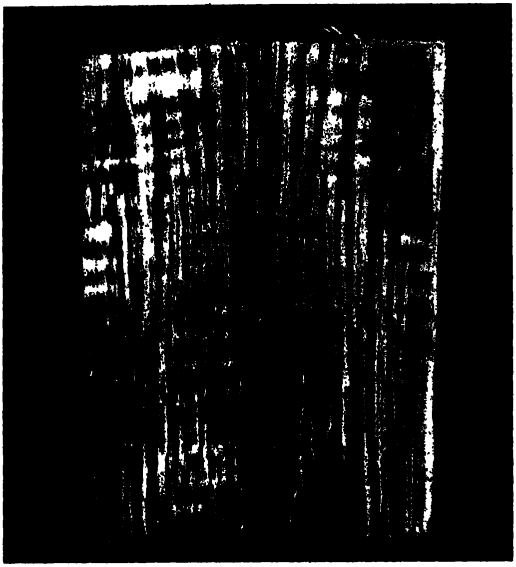


FIG. 1.—Split block showing wavy grain

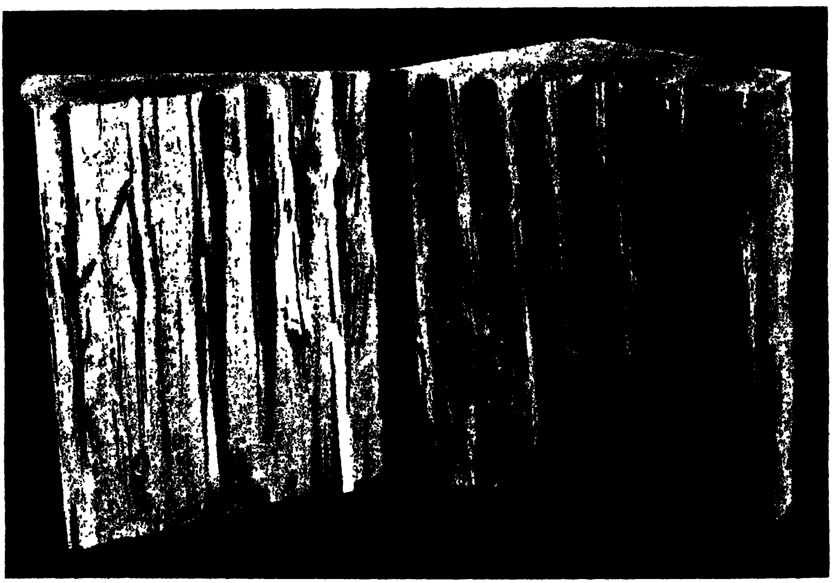


FIG. 2.—Split block showing interlocked grain

Photos by F.R.I., Kepong, Selangor, Malaya

rays broad, are said to be of coarse texture, but when the vessels are small, and the rays narrow, the timber is of fine texture. Many intermediate grades are met with, and some such classification as the following will be found useful:—*very fine*, *e.g.*, European box; *fine*, *e.g.*, sycamore; *medium*, *e.g.*, birch; *moderately coarse*, *e.g.*, walnut, mahogany; *coarse*, *e.g.*, oak. Strictly speaking, all softwoods are fine, or at most only moderately coarse-textured, as their cells are all of relatively small diameter, but a few with particularly thin-walled tracheids, *e.g.*, sequoia, may give a rather rough finish when sawn, and by comparison with the denser pines are distinctly coarse-textured.

The texture of softwoods is influenced by the alternation of the zones of early and late wood. When the contrast between the zones is strongly marked the wood may be said to be of **uneven texture**, *e.g.*, long-leaf pitch pine, Douglas fir, larch; when there is little or no contrast the wood may be said to be of **even texture**, *e.g.*, white pine, true firs, spruce. In this sense the terms may also be applied to hardwoods; ring-porous woods are uneven in texture, but diffuse-porous woods are even in texture unless broad rays or wide layers of wood parenchyma are present, when the texture may be as uneven as that of ring-porous woods.

Figure.—Several different types of figure have been mentioned in the discussion on grain, but many more than these are recognized in trade terminology. Those recorded are, however, the principal types arising from the type of grain present, and other kinds of figure are mainly modifications of the basic types. For example, **ram's horn** is a special form of wavy grain in which the waves are comparatively short, so that the resulting horizontal stripes are narrow and close together. Curls that resemble ostrich feathers are called **feather curl** as in crotch mahogany (Plate 31, fig. 3), and so on.

Figure also arises from the distribution of certain types of tissue in a wood: the broad high rays of the true oaks and "silky oak" are an example of figure — "silver figure" — derived from the particular distribution of the ray tissue in these woods. The alternating layers of dense late wood, and less dense early wood, produce the prominent "flame" figure of certain softwoods, *e.g.*, Douglas fir, when flat-sawn.

The distribution of the wood parenchyma in broad conspicuous layers, *e.g.*, species of *Millettia*, give rise to "flame"

figure, sometimes called watered-silk figure, when the timbers are flat-sawn, and similar figure is produced in timbers with alternating layers of different colour, *e.g.*, rengas and the striped ebonies. The presence of a particular type of grain, or the arrangement of certain types of tissues, is not in itself sufficient to ensure that decorative figure will be apparent, so long as the timber is correctly converted, *i.e.*, quarter-sawn or flat-sawn, depending on the source of the figure. The prominence and decorative effect of figure is dependent on the natural lustre of wood, *vide* page 66.

THE INFLUENCE OF THE DIRECTION OF THE GRAIN ON THE UTILIZATION OF WOOD

When the strength of timber is the primary consideration it is usual to specify that it shall be straight grained. The importance of this specification will be seen when it is realized that there is a reduction of about 4 per cent. in bending strength when the slope of the grain is 1 in 25; with a slope of 1 in 20 the reduction is 7 per cent.; with 1 in 15, 11 per cent.; with 1 in 10, 19 per cent.; and with 1 in 5, 45 per cent. The stiffness of a beam is also reduced by sloping grain, but to a less degree; the corresponding reduction in stiffness for the same variations of slope being respectively 3, 4, 6, 11, and 33 per cent. The percentage reductions in bending and stiffness vary somewhat with different species, but the figures quoted give an indication of the general trend. In consequence, it is recommended[1] that a slope of greater than 1 in 15 should not be permitted in beams; in flooring and in the smaller sizes of joists and rafters, on the other hand, where stiffness is generally of more importance than bending strength, a slope of 1 in 10 is usually permissible. Timber for tool handles and sports goods needs more careful selection, since a slope of only 1 in 25 causes a reduction of 9 per cent. in impact bending (shock-resisting abilities). Timber for such purposes should be as nearly straight grained as possible, and in no circumstances should the slope exceed 1 in 25. Even greater care is necessary in the selection of timber that is to be steam bent, as satisfactory bends cannot be made from other than straight-grained timber. The require-

ments of wood for barrel staves for tight cooperage illustrate another aspect of the importance of grain direction. Where the grain slopes from the inside to the outside of the cask there is a likelihood of the contents seeping through the staves, hence, straightness of grain is an essential quality in timber for this purpose.

It is not always easy to recognize that a piece of timber is not straight grained, particularly on the flat-sawn faces of timber with conspicuous growth rings, or on any face of timber without growth rings. A useful indication is given by the vessel lines, gum veins, resin ducts, and seasoning checks. In the absence of these features, and when it is impracticable to split the wood, the direction of the grain may be detected by raising a few fibres with the point of a penknife, or alternatively by noting the spread of an ink spot (see also Fig. 13).

COLOUR

From a practical viewpoint colour is of importance because it may enhance or detract from the decorative value of timber. Ebony, sycamore, mahogany, and walnut are notable instances in which the use of timbers has to some extent been determined by their colour or lack of it.

We have seen that colour is caused largely by various infiltrates in the cell wall. Some of the infiltrates in certain timbers, *e.g.*, logwood, are extracted for use as dyes. Some undergo changes when timber is exposed to light, air, or heat, with the result that many timbers darken with age, and others fade. Mahogany fades under strong sunlight, but darkens in moderate light; grey sycamore turns green in daylight, but not in artificial light. Several timbers, *e.g.*, teak and Borneo white seraya, exhibit quite a range of colour when freshly planed, but after a short exposure to daylight the colours even out considerably.

The moist heat employed during kiln seasoning darkens many woods, so much so that some are steamed purposely to alter the colour, *e.g.*, beech and walnut sapwood. Colour changes are also effected by chemical means, *e.g.*, liming lightens the colour and fuming (with ammonia gas) darkens it, removing the pink or red shades. Bleaching of wood with hydrogen peroxide is also feasible.

In an earlier section it has been mentioned that woods with

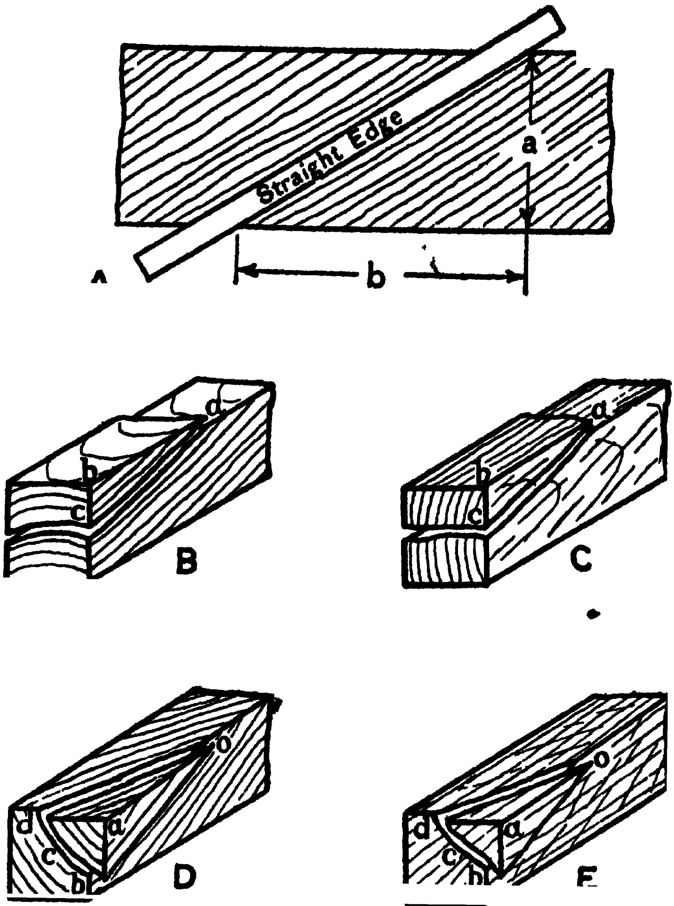


FIG. 13.—Measurement of the slope of the grain. A, B, and C, measurement of slope when the timber is truly quarter- or flat-sawn: slope $= \frac{a}{b}$ in A, and $\frac{bc}{ab}$ in B and C. D and E, measurement of slope when the timber is not truly quarter- or flat-sawn: slope $= \frac{ac}{ao}$, *ac* being perpendicular to the line *bcd* along a growth ring in D, and *bcd* being perpendicular to a growth ring in E.

By courtesy of the Commonwealth of Australia Department of Scientific and Industrial Research

a high tannin content are often very durable. Such woods, *e.g.*, oak, western red cedar, and merbau, all develop unsightly dark stains if they are allowed to come in contact with iron under moist conditions. Incidentally, they have a bad effect on the iron too, which is important in museum cases containing metal exhibits.

ODOUR AND TASTE

Many timbers have a characteristic odour, which is apparent when they are worked in a fairly fresh condition, but which usually disappears as the wood drys out. Perhaps the most outstanding examples are the characteristic resinous odour of the pines, the spicy aroma of sandalwood and Central American cedar, and the camphor-like odour of Formosan camphorwood. Certain Australian timbers of the *Acacia* group possess an odour not unlike violets, coachwood is reminiscent of new-mown hay, West Indian satinwood of coconut oil, and Queensland walnut has an objectionable foetid odour that disappears as the wood dries.

The taste of wood is closely related to odour, and can probably be traced to the same constituents. Both properties influence the utilization of timber: the choice of woods for food containers is, for obvious reasons, restricted to those without pronounced odour or taste, as it is undesirable that any odour or taste should be imparted to the food itself; the flavour of tobacco, on the other hand, is alleged to be improved when stored in Central American cedar boxes, although manufacturers would appear to attach little importance to the merit of the wood since they usually cover it with copious quantities of paper; and camphorwood is used for clothes-chests in the East because it is reputed to repel insect pests.

IRRITANTS

The infiltrates and cell contents of several timbers may give trouble to some wood-workers, and, in extreme cases, they may be the cause of certain illnesses in individuals. The most common complaint is that the "dust" of several woods irritates the mucous membrane, causing more or less violent sneezing, *e.g.*, sneezewood. Many woods induce dermatitis, which may be so severe as to incapacitate the worker for some days. Exceptionally, serious nose bleeding, or glandular swelling, may be induced, or asthma in those susceptible to this complaint. There is an ever-

growing list of timbers known to specialists in the field of Industrial Medicine as responsible for certain occupational diseases, although reaction to many woods is very much an individual idiosyncrasy. It is usually possible to isolate a particular substance, occurring as one of the ingredients among the infiltrates, as the causal agent of the deleterious properties of the wood.

Among timbers that have figured in the medical records are abura, agba, East Indian satinwood, iroko, makoré, mansonia, obeche, opepe, peroba, and teak ; the foregoing does not pretend to be in any way an exhaustive list. Timbers likely to head any " black list " are mansonia and makoré, although those who have had experience with them would no doubt rank dahoma, rengas, and tali high among timbers troublesome to wood-workers.

Improvements in dust-extraction plant in modern woodworking shops are assisting in minimizing inconvenience to operatives. Alternatively, it is often practicable to plan work so that relatively small quantities of the more objectionable timbers are put through the machines in one day. In this way mills have succeeded in cutting considerable quantities of mansonia without any inconvenience to their operatives. Exceptionally, it may be possible to protect exposed parts of the body with barrier creams or oil, as is done by Chinese operatives handling rengas and other timbers of the family *Anacardiaceae*. In rengas " the irritant " is the black sap that occurs in the radial intercellular canals. Sawdust from the sawing of unbarked logs of a few species, *e.g.*, melawis, is liable to cause intense skin irritations during sawing. Irritation from melawis is caused by the fine, needle-pointed cells in the inner bark.

LUSTRE

Lustre depends on the ability of the cell walls to reflect light. Some timbers possess this property in a high degree, *e.g.*, East Indian satinwood, lauan, and sapele, but others are comparatively dull, *e.g.*, hornbeam. As a general rule, quarter-sawn surfaces are more lustrous than flat-sawn, and if stripe, fiddle-back, or roe figure is present the figure is considerably enhanced in timbers possessing a natural lustre. Although lustre is an asset in a cabinet timber, from a practical viewpoint the capacity for taking a good polish is quite as important, and the two do not necessarily go hand in hand.

CHAPTER V

THE IDENTIFICATION OF TIMBERS

THE PROBLEM

The identification of timbers may, at first sight, appear to be a comparatively simple matter; when it is realized that there are over 20,000 woody species in the world it will be appreciated that in some cases correct identification may be exceedingly difficult. Actually it is not always possible to arrive at the correct specific name from the examination of a single sample of wood, although it is usually possible to narrow down the identification to a group of related species, and this may be sufficient for most practical purposes. Moreover, although there are so many species that produce woody stems, only a small proportion grow to timber size. Even so, the number of species producing commercial timber runs into some hundreds. The characters available for distinguishing woods are not numerous, and identification should be based on an examination of features that are known to be reliable, rather than on the more obvious characters, *e.g.*, colour and weight, that tend to be far from consistent.

THE PROCEDURE

The average timber user handles relatively few timbers and can usually recognize those with which he is familiar by a cursory glance; he is not, however, in a position to name timbers with which he is not familiar. On the other hand, it is often possible to arrive at the identity of an unfamiliar timber by a process of elimination along certain well-established lines. Each timber or group of very closely related timbers possesses a characteristic end surface; that is, the cells are so arranged as to produce a distinctive pattern. In theory, identification calls for the memorizing of these distinctive patterns. But just as one would

make little headway in learning Chinese characters without an understanding of the roots from which the characters are built up, so with timber identification, the components that give rise to the distinctive cell patterns must be thoroughly understood. The next stage is the development of sorting devices, which make use of the separate components, a similar problem to that facing finger-print experts: without a sorting device identification of other than the few common timbers is often a difficult matter even for the expert.

The apparatus required for identifying timbers may include a high-power microscope and the complete paraphernalia of a laboratory devoted to the study of wood, but for most practical purposes a sharp penknife or a razor blade and a small pocket lens, giving a magnification of 10 to 15 times, are all that is necessary. The first step is to prepare a small area of end surface by making a clean cut with the knife. The importance of using a really sharp knife and obtaining an absolutely clean-cut end surface cannot be overstressed. A blunt knife simply obscures structural details and a notched edge produces scratches which may be mistaken for rays or lines of parenchyma. From quite a small, clean-cut area of cross section it is possible with the aid of a lens to see a large amount of detail that is not visible on a rough surface with the naked eye. The method of making the cut is all important; it must be made in one action and not as a series of small jabs; the knife blade must be as nearly parallel with the end surface of the piece of wood as possible to ensure that the prepared surface is truly transverse and not oblique (a sharp knife tends to dig into the wood, producing a surface intermediate between the transverse and a longitudinal face); and the cut must be made along the rays from the bark towards the centre of the tree. A piece of wood about the size of a match-box is convenient to work with. A preliminary cut may be necessary to establish the direction of the rays on end surface. When this has been done the piece of wood should be held in the fingers, by the more nearly tangential faces, and a single cut made along the rays. If the cut surface is blurred under a lens, although the knife blade used was sharp, it is probable that the cut was made in the direction from the inside (of the tree) outwards. To overcome this, the piece of wood should be turned through an angle of 180°, and the cut repeated, when it will be

PLATE 34

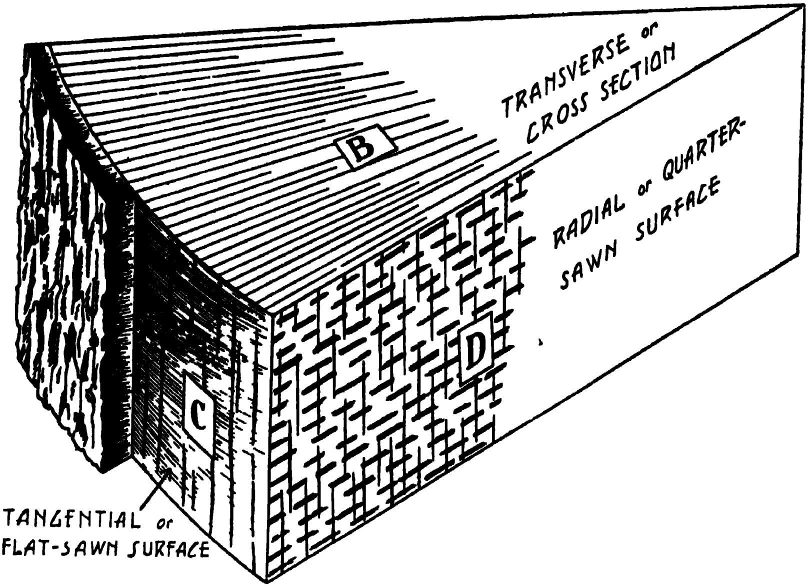


FIG 1 Diagrammatic drawing of a wedge of wood showing bark, and the relative positions of transverse, tangential, and radial surfaces The small squares lettered B, C, and D, are shown enlarged below

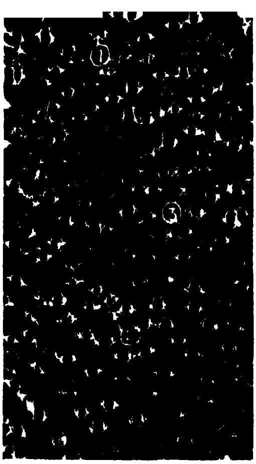


FIG 2 —Transverse section (× 5)

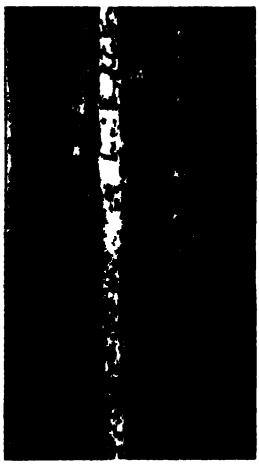


FIG. 3 —Tangential section (× 10)

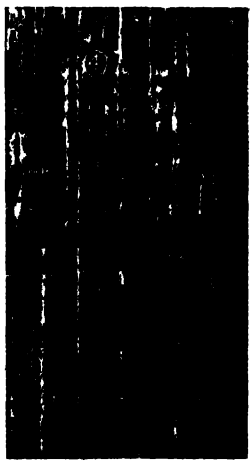
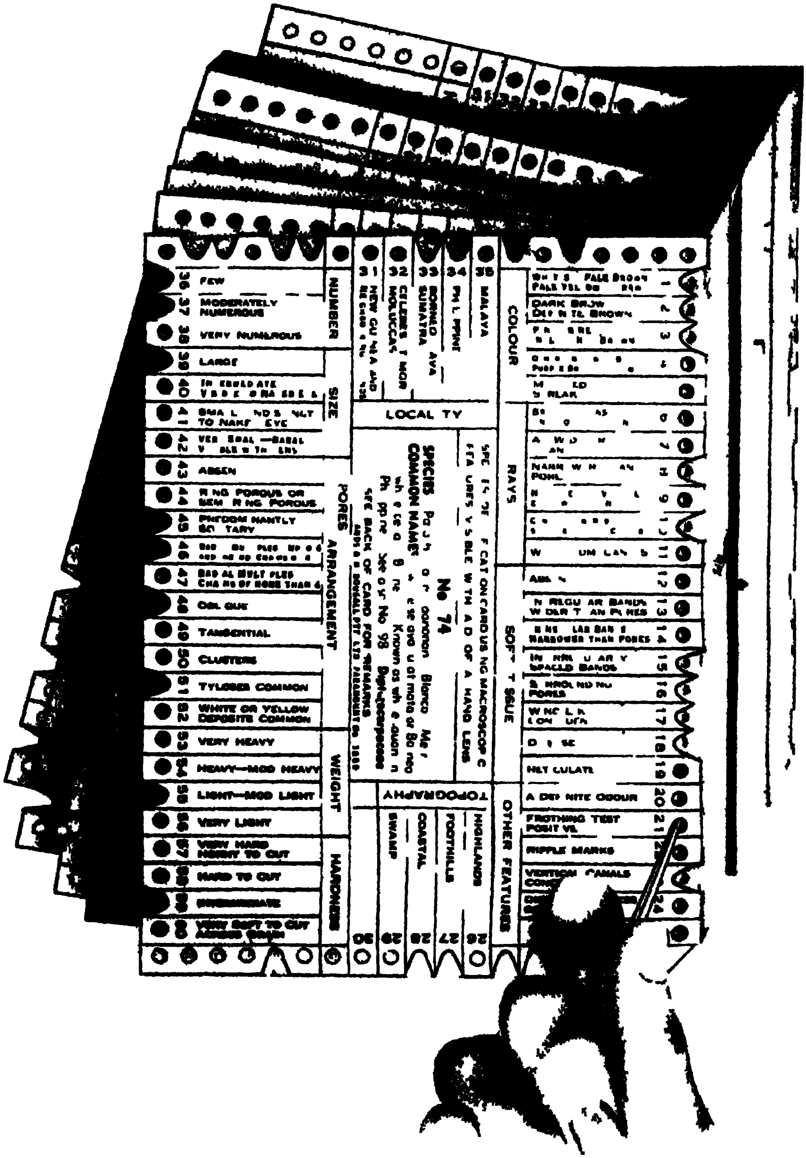


FIG 4 Radial section (× 5)

(1) vessels, (2)=parenchyma, (3)—rays, (4)—vessel lines

Fig 3, *photo by Rubber Research Institute, Kuala Lumpur*
Figs. 2 and 4, *photos by F R I, Kepong, Malaya*

PLATE 35



The multiple entry card key in operation

By courtesy of the Cleaver Hume Press Ltd

along the rays, but in the correct direction, *i.e.*, from the bark towards the centre of the tree. If no face of the wood is sufficiently radial it may be necessary to trim the block to ensure a transverse cut being made along the rays. After the end surface is prepared, the subsequent procedure depends on several circumstances, and only general principles can be discussed here.

The relative positions of the three surfaces of wood, transverse, radial, and tangential, often confuse the beginner: Plate 34, fig. A, clarifies this point. Figs. B, C, and D of Plate 34 show how different the three surfaces of the same wood can appear.

In every case the first point to decide is whether vessels are present or not; this settles to which of the two main classes of timber (hardwoods or softwoods) the sample belongs. Next, the type of growth rings, or their absence, and then the presence or absence of resin canals are helpful features. The examination of a sample for these three features alone narrows the range appreciably. Other features, such as the type of rays, the distribution of the parenchyma, weight, hardness, and colour, are used in turn. Such features as wood parenchyma and rays are often more apparent if the cut-surface of the wood is moistened.

The procedure outlined above is the basis of all keys to the identification of timbers. Keys are artificial devices, leading to correct identification by arbitrary means, *i.e.*, a consideration of unrelated features in the most advantageous sequence. The commonest form of key in general use in botanical and entomological work is the dichotomous key, whereby successive pairs of mutually exclusive conditions are so arranged that, by a process of elimination, one is led step by step to the identity of the specimen. Such keys are suitable for a restricted number of timbers, plants, or insects: they become unmanageable if their construction is attempted for too many different individuals, because it is frequently necessary to use features that are subject to considerable variation within a single species, and it becomes increasingly difficult to find pairs of characteristics that are mutually exclusive. In some circumstances it is often necessary to include the same timber, plant, or insect in more than one section of a key to ensure covering variation within a species, or the lack of really satisfactory, mutually exclusive, characters.

TABLE I

Tabular list of hardwood features visible to the naked eye or with the aid of a hand lens

(The number of features used may, of course, be considerably enlarged)

Name of timber	Vessels							Parenchyma											Other features			Rays				Physical properties		
	Exclusively solitary	Radial multiples	Pore clusters	Scalariform perforations	Distinct to naked eye	Distinct only with lens	Barely visible with lens	Absent or indistinct	Distinct to naked eye	Terminal prominent	Apparently terminal only	Vasicentric	Aliform	Confluent	Banded	Broad conspicuous bands	Fine lines	Reticulate	Normal vertical canals	Ring porous	Storeyed (not rays)	> ½ width of vessels	Wider than vessels	Storeyed	Aggregate rays	White	Yellow or brown	Red or purple
Ash	−	−	−	−	+	−	−	−	−	+	−	+	±	±	−	−	−	−	−	+	−	−	−	−	−	+	−	−
Dahoma	−	−	−	−	+	−	−	−	+	+	−	+	+	−	−	−	−	−	−	−	−	−	−	−	−	−	+	−
Ebony	−	+	−	−	−	+	−	−	−	−	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	+	+
Ekki	−	−	−	−	+	−	−	−	+	−	−	−	−	−	+	+	−	−	−	−	−	−	−	−	−	−	−	+
Elm	−	−	+	−	+	−	−	+	−	−	−	−	−	−	−	−	−	−	−	+	−	−	−	−	−	−	+	−
Gaboon	−	−	−	−	+	−	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	−	−
Gurjun	+	−	−	−	+	−	−	±	−	−	−	×	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−	+
Idigbo	−	−	−	−	+	−	−	−	+	×	−	+	+	+	−	−	−	−	−	−	−	−	−	−	−	+	+	−
Iroko	−	−	−	−	+	−	−	−	+	+	−	+	+	+	−	−	−	−	−	−	−	−	−	−	−	−	+	−
Mahogany — Central American	−	−	−	−	−	+	−	−	+	+	−	×	−	−	−	−	−	−	−	−	−	−	−	+	−	−	−	+
Mahogany — African	−	−	−	−	+	−	−	+	−	−	−	×	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+
Makoré	−	+	−	−	−	+	−	−	−	−	−	−	−	−	+	−	−	+	−	−	−	−	−	−	−	−	−	+
Meranti	−	−	−	−	+	−	−	−	−	−	−	+	±	±	−	−	−	−	+	−	−	−	−	−	−	−	−	+
Obeche	−	−	−	−	+	−	−	−	−	+	−	+	−	−	−	−	+	−	−	−	+	−	−	−	−	+	+	−
Opepe	+	−	−	−	+	−	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	−
Oak	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−	−	+	±	−	+	−	+	+	−	−	−	±	±
Sapele	−	−	−	−	−	+	−	−	+	+	−	+	+	+	±	−	−	−	−	−	−	−	−	+	−	−	−	+
Teak	−	−	−	−	+	−	−	−	−	×	−	+	−	−	−	−	−	−	−	+	−	−	−	−	−	−	+	−
Walnut — African	−	−	−	−	−	+	−	±	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	+
Whitewood — American	−	−	−	+	−	−	+	−	−	+	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	−

As a preliminary to the construction of a dichotomous key, it is an advantage to list the features present in every timber to be included in the key; to facilitate subsequent work the list should be in tabular form. Because the features used are so different, it is necessary to prepare separate lists, and therefore to construct separate keys, for softwoods and hardwoods.

The procedure in preparing a table of features is to allot one column for each feature, either across or along the side of a piece of paper, and to have a column for the timbers (Table I). Opposite each timber, and in the appropriate column, a cross is put if the feature occurs and a minus sign if the feature is wanting. If the occurrence of the feature is variable in different specimens of the same timber an alternative sign, *e.g.*, ±, may be used to denote this. In such cases it is necessary to bring out the timber in two places in the key if this feature is used before the timber has been excluded on some other score. A multiplication sign × may be used to indicate that a particular feature is indistinct.

In preparing a dichotomous key the table provides an easy means of seeing at a glance those timbers that can be run down quickly: the columns with few crosses indicate features that will eliminate a few timbers in the early stages of the key. The subsequent sequence is immaterial, but it will be found more satisfactory to use the more clear-cut features before the more ambiguous ones, *i.e.*, features that are easy to recognize and not ones that are open to personal interpretation. The dichotomous key that follows has been constructed from the data in Table I — more than one key could, of course, be constructed from the same data by taking successive features in a different order.

1	Wood ring-porous	2
1	Wood not ring-porous	5
2	Pore clusters present (parenchyma absent or indistinct)	Elm
2	Pore clusters absent	3
3	Rays wider than vessels (parenchyma in fine lines)	Oak
3	Rays not wider than vessels	4
4	Wood white (no odour)	Ash
4	Wood brown (distinctive odour)	Teak
5	Vessels exclusively solitary	6
5	Vessels not exclusively solitary	7

6	Normal vertical canals present	Gurjun
6	Normal vertical canals absent	Opepe
7	Scalariform perforation plates distinct	American whitewood
7	Scalariform perforation plates indistinct or absent	8
8	Ripple marks distinct	9
8	Ripple marks indistinct or absent	10
9	Confluent parenchyma present	Sapele
9	Confluent parenchyma absent	Central American mahogany
10	Vessels in radial groups	11
10	Vessels not in radial groups	12
11	Parenchyma banded, wood red-brown	Makoré
11	Parenchyma not banded, wood yellow or black, or streaked brown-black	Ebony
12	Normal vertical canals present	13
12	Normal vertical canals absent	14
13	Canals in short tangential series	Gurjun
13	Canals not in short tangential series	Meranti
14	Tissue other than rays storeyed	Obeche
14	Tissue other than rays not storeyed	15
15	Parenchyma in broad conspicuous bands	Ekki
15	Parenchyma not in broad conspicuous bands	16
16	Parenchyma distinct to naked eye	17
16	Parenchyma not distinct to naked eye	20
17	Wood white or yellow (terminal parenchyma indistinct)	Idigbo
17	Wood not white, terminal parenchyma prominent	18
18	Parenchyma apparently terminal only	Central American mahogany
18	Parenchyma not apparently terminal only	19
19	Confluent parenchyma present	Iroko
19	Confluent parenchyma absent	Dahoma
20	Wood walnut-brown	African walnut
20	Wood not walnut-brown	21
21	Wood pink-brown to red-brown, rays just visible to naked eye	African mahogany
21	Wood light pink, rays distinct only with lens	Gaboon

In using this key one takes the first pair of conditions: if the sample for identification is ring-porous, one proceeds to question 2, and if diffuse-porous, to question 5. It will be seen that the same question can be used more than once in different sections of the key, *e.g.*, gurjun is brought out under exclusively solitary vessels

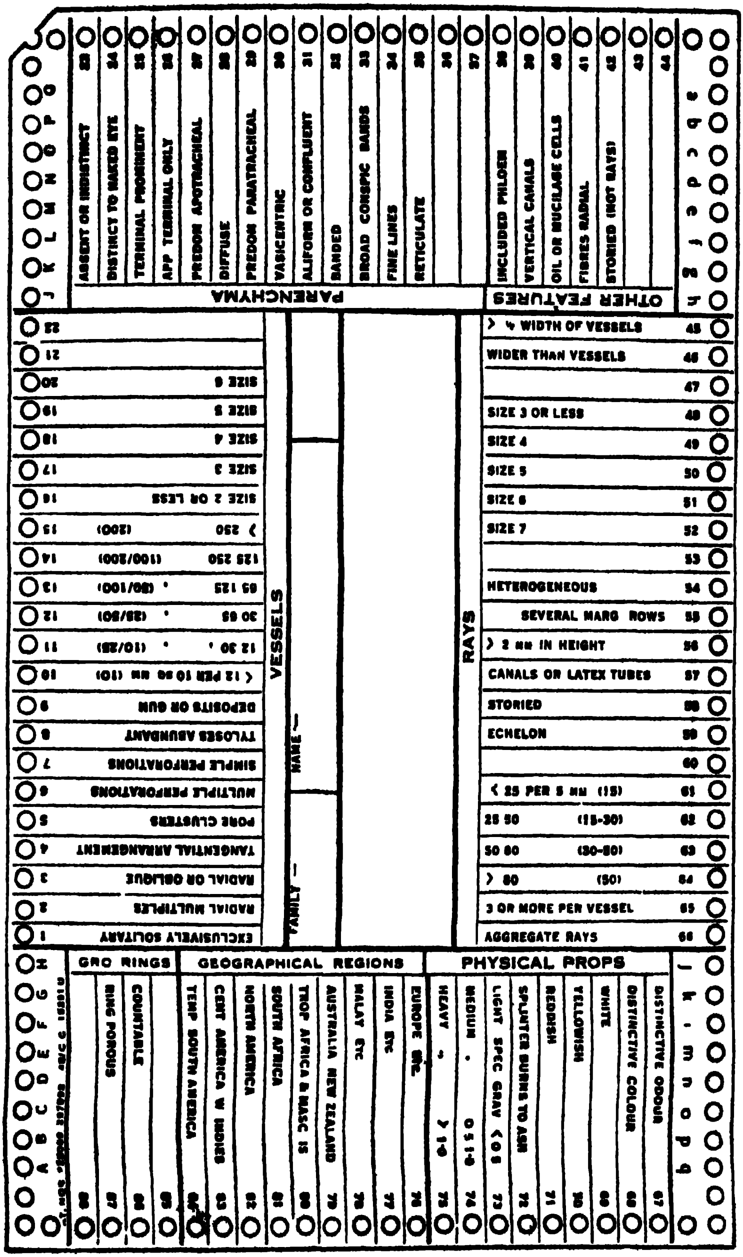


FIG. 14.—A Paramount card used in multiple entry card keys. The card illustrated is for a key based on lens features
By courtesy of Messrs. Copeland-Chatterson Co. Ltd.

and normal vertical canals, and meranti under vessels not exclusively solitary, but normal vertical canals present, much later in the key.

Timbers are so numerous, and the differences between many are so small, that it is impossible to construct a workable dichotomous key to embrace all the timbers in the world. Several good keys exist that are restricted to the timbers of particular countries or localities. For example, Chalk and Rendle's key to British hardwoods,[1] Record's key to North American timbers,[2] Dadswell's keys to Australian timbers,[3] and Brown's key to Indian timbers,[4] are excellent for the timbers they embrace. All dichotomous keys have the disadvantage that additional timbers cannot be included in the key without reconstruction of large sections, if not the greater part, of the key.

Mr. S. H. Clarke, C.B E., M.Sc , when a wood anatomist at the Forest Products Research Laboratory, adapted the Paramount sorting system to timber identification in his aptly named multiple entry key. Special cards, patented by Messrs. Copeland-Chatterson Co., Ltd., containing punched holes along their four sides, are employed ; each hole is used for one feature (Fig. 14). Every timber to be included in the key requires a separate card and, if certain features are variable in different samples of the same timber, two or more cards may be necessary, exceptionally as many as eight cards. The card is completed for each timber by punching the holes for the features present in the wood with a special punch that cuts a V-shaped slot from the original punched hole. When all the cards are prepared they are sorted so that all are arranged the same way round and the key is ready for use. To facilitate rapid sorting it is convenient to cut one corner of each card on the splay, *e.g.*, the top right-hand corner as in the cards patented by Messrs. Copeland-Chatterson.

Mr. B. J. Rendle, B.Sc., and his colleague Dr. E. W. J. Phillips of the Forest Products Research Laboratory have prepared the data for a set of cards for more than 400 commercial timbers ;

[1] *British hardwoods*, Forest Products Research Bull. No. 3, H.M. Stationery Office.

[2] *Timbers of North America*, by S. J. Record. John Wiley & Sons, 1934.

[3] Bulls. Nos. 67, 78, and 90, Council for Sci. Ind. Research, Commonwealth of Australia, Melbourne.

[4] *An elementary manual of Indian wood technology*, by H. P. Brown. Calcutta, Gov. India Central Publ. Branch, 1925.

this information has been published as a Forest Products Research Laboratory Bulletin — No. 25 — and blank cards, albeit on rather thin paper, are available from H.M. Stationery Office. In using the data it is important to appreciate just how the definitions of different anatomical features are used since some of the terms, *e.g.*, fine lines, are used in a slightly different sense from the definitions given in Chapter III.

To identify a timber, any feature present in the specimen is selected and a steel needle threaded through the punched hole for the selected feature (Plate 35 [1]). The cards for those timbers in which the selected feature occurs drop out as the needle is shaken. These cards are again sorted so that they are all the same way round, a second feature is selected, the needle threaded, and the shaking process repeated. The cards that drop out on the second occasion are again sorted and the process continued with different features in turn until only one or a few cards remain: provided a card for the specimen to be identified has been prepared it will be among those finally eliminated. With some timbers the card-key system results in the elimination of all cards but one, although more often a selection has to be made from two or three cards, because it is not possible to include all features on the card, and interpretation of a few features is largely a matter of personal opinion. However, when selection is narrowed to two or three timbers, correct identification can usually be arrived at by matching the unknown timber with authenticated specimens of the few alternative choices. In working with a card-key of this type three precautions must be observed: (1) in shaking the pack, care must be taken to ensure that all the cards free to drop out do, in fact, drop out; (2) care must be taken that the correct pack is used after each sorting, *i.e.*, if a feature is being used positively the cards that drop out are used for the next operation, and *vice versa*; and (3) the cards must be kept in good condition, *i.e.*, should any of the punched holes become torn a new card must be made out.

The two special advantages of the card-key system are: (1) the simplicity with which new timbers can be added to the key — all that is required is an additional card, and (2) any

[1] Plate 35 depicts a modified multiple entry card-key, which, however, is operated identically. The particular key was developed by the Australian Forest Products Laboratory for use on the Pacific front in the 1939–45 War.

sequence can be adopted that promises speedy identification.

It is usual to confine keys to features visible only with the aid of a microscope or to features visible to the naked eye or with the aid of a low-power hand lens, but there is no reason why a key should not combine both classes of features, although such keys can, of course, only be used in the laboratory. In a lens key it is desirable to record features as they appear, whether or not the observations are in accord with the facts. For example, the line of tissue bordering a growth ring in beech is not terminal parenchyma, but it is convenient to record it as such because, with a lens, it is rather difficult to establish that it is not true terminal parenchyma. Actually, the line consists of a few rows of radially-flattened fibres, wanting in diffuse parenchyma, and this zone contrasts with the remainder of the fibre-diffuse parenchyma background to give the effect of a line of distinctive tissue.

The successful use of keys necessitates some experience in the examination of small samples of wood, and this can only be obtained by practice. Readers who are anxious to be in a position to identify any but the few common timbers in everyday use would be well advised to make their own keys from a study of a collection of authentic samples of timbers. As a preliminary to a concerted attack on the problem of identification, there is no better method than the preparation of scale drawings of the end surfaces of different woods. The procedure is to prepare a clean-cut portion of the end surface, and to mark on this a square with one-centimetre sides. Next, a sheet of paper with a square of five-centimetre sides is required. The details visible in the marked square can then be transferred to the paper, more or less to correct scale. It is usually helpful to commence with the rays, and then to draw in the vessels, and subsequently the other details. The method is admittedly laborious, but the preparation of thirty or forty drawings fixes the distinctive patterns of the woods in the mind, and is of great help in mastering the technique of timber identification.

Finally, it may not be inappropriate to comment on the different ways of expressing magnification. It is not always easy to appreciate the significance of $\times 10$, $\times 15$, $\times 30$. An added complication is introduced by makers inscribing the magnification of pocket lenses on a different system from other optical equipment.

Whereas it is usual for the magnification of microscopes and text-book illustrations to be in terms of linear dimensions, pocket lenses are usually inscribed in terms of area magnification. Thus a $\times 10$ pocket lens is a linear magnification of $\sqrt{10}$, or just over 3 linear, whereas a text illustration $\times 10$ is equivalent to an area magnification of 10^2 or 100. The frontispiece will, it is hoped, clarify the problem of scale.

The top three squares are designated in terms of area magnification, and the bottom four squares in terms of linear magnification. In both series the squares on the extreme left are "natural size", or $\times 1$ magnification. The next square to the right in both series is enlarged, *to scale*, at the magnification given. That is, the square in the top series marked $\times 10$ is the size the square marked "$\times 1$" becomes when magnified $\times 10$ area magnification; that marked $\times 15$, the size when the "$\times 1$" squared is magnified $\times 15$ area magnification. Similarly, the first two squares to the left of the "natural size" square in the lower series are drawn magnified $\times 2$ and $\times 5$ linear magnification respectively, and the portion of the $\times 5$ square outlined in white is drawn to scale, magnified $\times 30$. It will be observed that $\times 5$ linear magnification is an appreciably higher magnification than $\times 10$ area magnification—the relation is 5 to $\sqrt{10}$ or 5 to 3·16. The largest magnification, using a hand lens, that it is convenient to work with for any continuous period is an area magnification of $\times 15$; an area magnification of $\times 20$ is the extreme limit of magnification for hand lenses—beyond this the field is too small and the hand is insufficiently steady to permit of keeping the "object" being examined in focus. Comparison of the amount of detail visible in the section of oak $\times 5$ linear magnification (*i.e.*, $\times 25$ area magnification) with that visible at $\times 10$ linear magnification (Plate 19, fig. 3) will make it apparent that there are very real limitations to the anatomical study of wood with a pocket lens. Nevertheless, with practice, it is possible to see a great deal, often not as clear-cut as could be desired, but sufficient for purposes of identification.

PART III

THE PROPERTIES OF WOOD

CHAPTER VI

THE MOISTURE IN WOOD

DETERMINATION OF MOISTURE CONTENT

The timber of living trees and freshly felled logs contains a large amount of water, which often constitutes a greater proportion by weight than the solid material itself. The water has a profound influence on the properties of wood, affecting its weight, strength, shrinkage, and liability to attack by some insects and by fungi that cause stain or even decay.

Since the properties of timber depend so much on the amount of moisture it contains it is frequently necessary to know the exact moisture content of a particular sample, *i.e.*, how much water is present in the sample. The amount of moisture present in converted wood varies appreciably in different circumstances, but the dry weight of wood substance in a given sample is constant. Hence, it is usual to express the variable — moisture content — as a percentage of the constant — dry weight of the sample. The ratio is simply:

$$\frac{\text{Weight (or volume) of water present}}{\text{Dry weight of wood substance}} \times 100.$$

There are several ways of determining the moisture content of wood, but by far the most satisfactory for most purposes is the oven-dry method described below.

Oven-dry method.—In this method, the moisture content of the moment is obtained as follows:

$$\frac{\text{Initial wt of sample} - \text{dry wt of sample}}{\text{Dry weight of sample}} \times 100.$$

The initial weight of a sample is the actual weight at the time of test, and the dry weight is the weight of the sample after the moisture has been expelled.

Apparatus.—The apparatus required is a simple balance, and

some form of drying oven that can be maintained at a more or less constant temperature. The type of balance suitable in commercial practice is one of the self-registering type, weighing to an accuracy of 0·5 gram and up to a maximum of about 500 grams. The metric system is recommended, as it simplifies the calculations; otherwise English units will do equally well. Various types of drying ovens are on the market, but all are essentially similar in principle, in spite of makers' claims to special advantages. The essential points to look for are: (1) the capacity of maintaining an even temperature between 95° and 105° C. (205°-220° F.); (2) good ventilation (a sample heated in a closed box would, of course, not lose moisture once the surrounding air space had become saturated); and (3) source of heat. For heating, electricity has the advantage of simplicity, but gas, oil, or steam may equally well be used; it is entirely a matter of convenience. Designs of simple ovens, one electrically and the other steam heated, are given, and their method of construction described, in leaflets issued by the Forest Products Research Laboratory, Princes Risborough. The one illustrated in Plate 36, manufactured by Messrs. W. and J. George & Becker Ltd., is to the Princes Risborough Laboratory's design.

Sampling.—Provided attention is paid to the essential points enumerated above, the method of selecting test blocks is of greater importance than any particular features of the apparatus used for weighing and drying the samples. It is essential that the sample shall be representative, not only of the board or plank from which it is cut, but also of the parcel as a whole. For example, the moisture content of the sapwood of some species varies appreciably from that of the heartwood, so that the proportion of sapwood in the test blocks should be similar to that in the whole parcel. In practice, the moisture content of a large quantity of timber should not be based on a single sample, but on two or three selected at random. When taking sample boards from a stack of timber outside ones should be avoided, as these often differ appreciably in moisture content from those of the interior. Having selected the samples, off-cuts of the full cross section of each sample should be taken not less than 9 to 12 in. (preferably 2 ft) from either end, and [illegible] to [illegible] in. along the grain. Larger pieces take much longer to dry, and are not necessary. Each sample should be reasonably free from

knots: although their actual influence on moisture-content determinations is not known, they are not typical of the wood as a whole; in some softwoods, for instance, they may have a high resin content, and the resin may run out during oven drying.

Procedure.—Once the test block has been cut out, rapidity of weighing is essential to minimize the chance of the sample picking up, or losing, moisture between the time of cutting and that of weighing, since small moisture losses or gains during this interval will introduce appreciable errors in the calculated moisture content, and such losses or gains are much more rapid in the small-sized samples used for moisture-content determinations than they are in the boards or planks from which the samples are cut. After the initial weighing the samples should be transferred to the drying oven. This should be run at a temperature of 60° C. for the first few hours to prevent the moisture in the centre of the samples from being sealed in, as a result of case-hardening.[1] The temperature can be raised to 102° afterwards, and the samples left in the oven overnight. They should be re-weighed first thing on the following morning, and again some hours later. Rapidity of weighing is of particular importance when the samples are oven dry, as, in this state, they will absorb moisture in a very short space of time. If there is no appreciable difference between the last two weighings, the lower may be taken as the oven-dry weight. If, however, the second weighing shows an appreciable drop, drying must be continued for a further period. Drying in an oven does not expel all the moisture, but the small discrepancy — the last one per cent. or so — is not of practical importance.

Example.—A test block with an initial weight of 88·7 grams weighed 76·7 grams twenty-four hours later, and 76·6 grams four hours later still. Accepting the second of these re-weighings as the dry weight, the moisture content of the sample was:

$$\frac{88{\cdot}7 - 76{\cdot}6}{76{\cdot}6} \times 100, \text{ or } \frac{12{\cdot}1}{76{\cdot}6} \times 100 = 15{\cdot}8 \text{ per cent.}$$

Single calculations of moisture content may be sufficient for determining whether a stack of timber is suitable for a general purpose, *e.g.*, indoor or outside use, but occasions will often arise

[1] See page 205 for a definition of case-hardening.

when it is desirable to determine moisture contents of the same material from time to time over a period. This is the case, for example, when studying the progress of seasoning in a stack. Such work can be greatly simplified if test boards are so arranged in the stack that they can be withdrawn without disturbing the stack on each occasion. This can be achieved by notching the stickers (the slats of wood used for separating the layers of timber in a stack) above the test boards, so that the latter are free to move. Having estimated the moisture content of the test boards from samples cut in the normal way at the time of the first test, the moisture contents can be calculated on subsequent occasions from re-weighing of the boards alone.

Example.—The initial weight of a test board is 51 lb., and its moisture content, as determined from samples, is 27·5 per cent. Let its dry weight equal "x", then $x + \frac{27 \cdot 5x}{100} = 51$, and $x = 40$. After a lapse of a week the board is re-weighed and found to scale 48·3 lb. We know the dry weight from the previous calculation, so that the moisture content of the moment can be determined by substitution in the formula

$$\frac{\text{Present weight} - \text{dry weight}}{\text{Dry weight}} \times 100$$

in this case —

$$\frac{48 \cdot 3 - 40 \cdot 0}{40} \times 100 = 20 \cdot 8 \text{ per cent.}$$

The process can be repeated as often as is required during the seasoning period.

Distillation method.—The presence of oils or resins introduces an error in the calculated moisture content because these substances, being volatile, are lost in the process of drying, and are counted as moisture, so that the calculated figures are too high. This should be borne in mind when dealing with such timbers as gurjun, apitong, keruing, and resinous samples of long-leaf pitch pine or timber impregnated with an oil preservative such as creosote. Moisture-content determinations in such circumstances can be accurately determined by the distillation method.

In this method the sample takes the form of about 50 grams of chips, borings, or sawdust. The sample is placed in a flask containing a water-insoluble oil of low density; xylol is the one most often used. The apparatus employed is illustrated in

Fig. 15. It consists of a flask, with suitable heating arrangements, a reflux condenser discharging into a graduated trap that collects the condensed water from the wood and returns the solvent oil to the flask. Distillation is continued until no more water collects in the trap. The volume of water collected

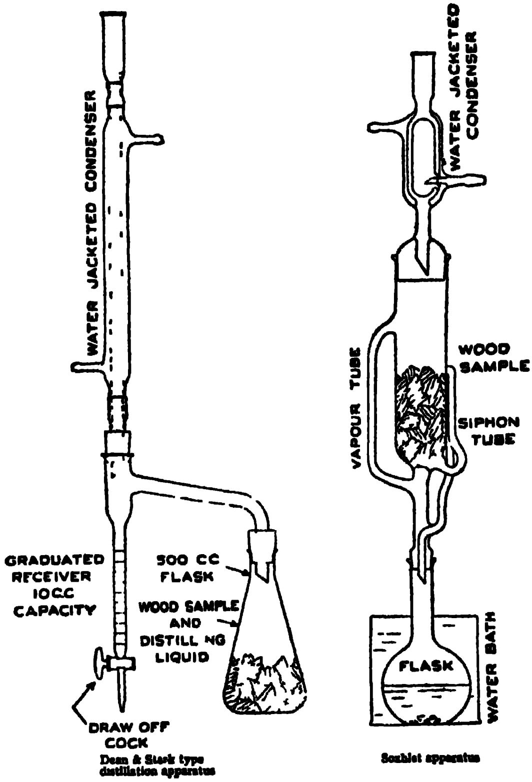


FIG. 15 --Distillation method of moisture-content determination alternative types of apparatus

By courtesy of the Director, F.P.R.L., Princes Risborough

is read direct in cubic centimetres. As one cubic centimetre of water weighs one gram, the weight of water in the sample is obtained automatically. With samples containing only natural oils or resins, the moisture content is arrived at simply as follows:

$$\frac{\text{Wt in grams of water collected}}{\text{Initial wt of the wood sample} - \text{Wt in grams of water collected}} \times 100$$
$$= \text{per cent. moisture content of sample.}$$

Samples of impregnated wood contain, in addition to wood

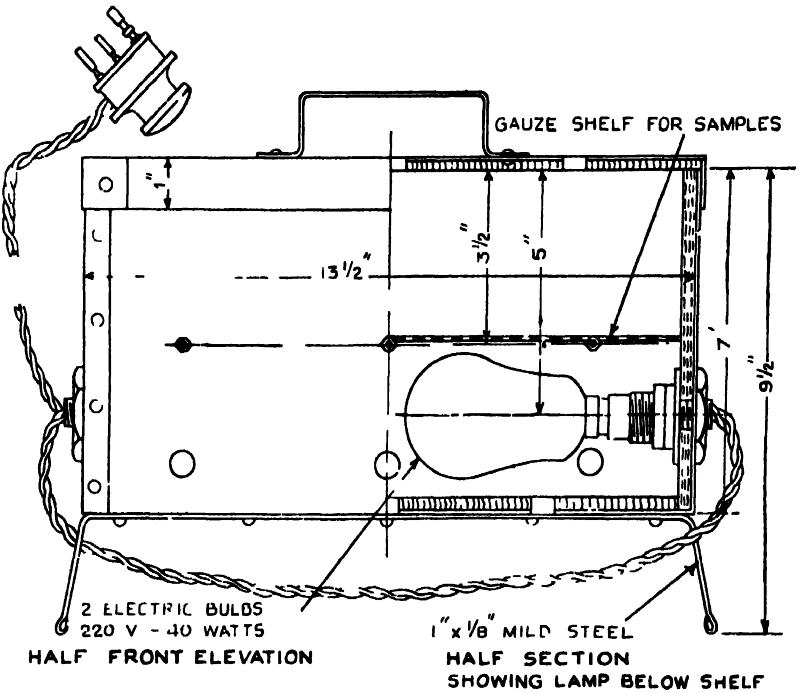
substance and water, an unknown weight of preservative. This weight must next be determined, and is done by extraction of the preservative, with a suitable solvent, from the liquid remaining in the flask at the end of the initial distillation process. The moisture content of the treated wood can then be calculated :

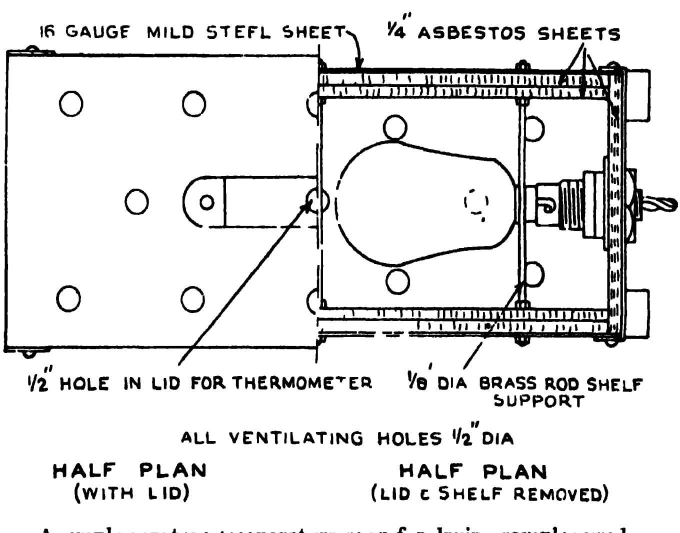
$$\frac{\text{Wt in grams of water collected}}{x-(\text{Wt of preservative}+\text{Wt in grams of water collected})}\times 100$$
$$=\text{per cent. moisture content of sample,}$$

where x is the initial weight of wood sample.

The distillation method probably gives more accurate results than the oven-drying method for any wood, but the delicate apparatus required, and the risk from fire that heating xylol entails, render it suitable for use only in properly equipped laboratories. Such laboratories are not normally to be found, nor are they required, in ordinary commercial layouts. Even with timbers such as gurjun, the oven-drying method gives moisture-content values within about 1·5 per cent. of the true values, which is accurate enough for most purposes for which such timber is used. Moreover, it is easy for errors to creep in with the distillation method: chips of wood, borings, and sawdust, unless carefully and rapidly weighed after collection, may quickly lose moisture, so that the calculated moisture content is below that of the piece from which the sample was taken. It is, however, necessary to use chips or their equivalent to ensure that all the contained moisture is completely and rapidly extracted. The small size of the sample makes complete extraction of water essential, even minute quantities retained in the wood would appreciably magnify the errors in the calculated moisture content. A sample of 50 grams has been found convenient to work with; smaller ones might magnify errors unduly, and larger ones involve inconveniently cumbersome apparatus. Besides accuracy, the distillation method has the advantage of rapidity: distillation should take only three or four hours.

Moisture meters.—The moisture content of wood may be determined indirectly by measuring some other property that varies proportionately with changes in moisture content. For example, the electrical resistance of wood is an index of its moisture content. Fortunately, the range over which a close





A simple constant-temperature oven for drying samples used in moisture-content determinations

By courtesy of the Director, F.P.R.L., Princes Risborough

FIG. 1 Moisture in timber meter, resistance type

By courtesy of Messrs. Marconi Instruments Ltd.

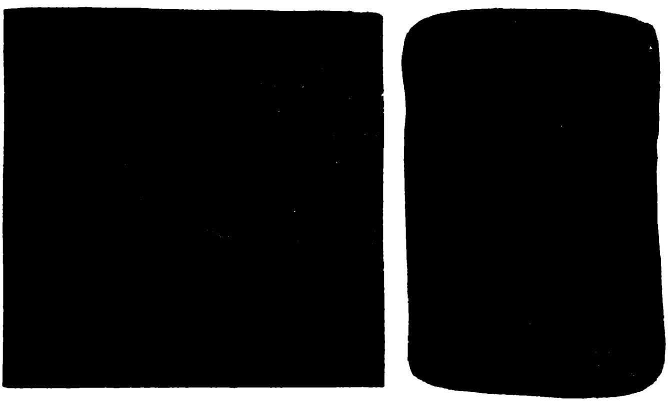


FIG. 2 Compression set induced experimentally. The left hand 1 in. cube of mahogany was subjected to 15 wetting and drying cycles. Each time prior to soaking the cube was lightly clamped so that it could not expand when picking up moisture. After soaking the cube was dried each time to 12 per cent moisture content, re-clamped, and re-wetted. At the end of 15 cycles the cube was reduced to the size illustrated on the right.

By courtesy of The Airscrew Company and Jicwood Ltd., Weybridge, Surrey

relationship exists is that from about 6, up to 24, per cent. moisture content, and this fact makes the measurement of electrical resistance or conduction by means of electrical moisture meters practicable.

Electrical moisture meters have been developed beyond the laboratory stage: they have been in commercial use for several years. Two general types of instruments are made: one evaluates moisture content by measuring electrical resistance, and the other determines the electrical capacitance of wood.

The resistance type of machine has electrodes in the form of spikes, which are driven into the wood. The electrical conductivity of the wood is used as an index of moisture content, which, in some instruments, is directly read from a scale. In the capacity type of instrument surface plates are clamped on opposite faces of the timber and the capacitance between the plates is balanced against a variable condenser.

Instruments can be obtained that will indicate by the frequency of flashing of a neon tube whether the wood is drier or wetter than a predetermined standard; or, alternatively, the moisture content may be indicated directly on a scale.

Several electrical moisture meters of the resistance type are available on the market; an instrument of British manufacture is illustrated in Plate 37, fig. 1. Any equipment capable of measuring the very high resistances involved, when fitted with a suitable electrode assembly for making contact with the wood, and calibrated, can be used within the limitations of this method of moisture-content determination. For example, an ordinary insulation testing set, capable of reading up to 1000 megohms, can be adapted to read moisture contents from about 11 per cent. to fibre saturation point.[1]

Resistance varies with the temperature, increasing with a falling temperature, and decreasing with a rising temperature. Moreover, the resistance for any given moisture content and temperature is not constant for different species. Hence, corrections have to be made for temperature and species. This is fortunately not difficult to do with sufficient accuracy for practical purposes; instruments are usually supplied with the necessary correction data by the manufacturers.

Besides the question of cost, and the fact that a different

[1] For definition of fibre saturation point see page 89.

scale, or correction factor, has to be used for each species, resistance moisture meters have other limitations. In the first place, the figure read off the scale is the moisture content of the piece to the depth of penetration of the electrodes, or, with contact instruments, the surface of the piece. In the early stages of drying, the surface moisture content of a board or plank is likely to be very different from that of the interior, and with thick timbers this is likely to be so always, so that the meter reading gives too low a figure for the piece as a whole. On the other hand, a surface film of water left by a shower of rain will cause the reading to be too high. In the second place, the instruments are delicate, and require careful handling and considerable technical knowledge to maintain them in an efficient condition. Moisture meters, however, have distinct commercial possibilities: they give results almost instantaneously, and when appropriately used will give readings within one per cent. of the true values. Moreover, they provide the only practicable means of determining the moisture content of finished woodwork *in situ* without damaging the wood. Moisture meters are particularly suitable for sorting veneers on moisture content, but they have a much wider use provided the operator appreciates their limitations, and is constantly using them for the same class of work. In effect, as a handmaid they can be extremely useful for thin dimension stock, but they are not so suitable when used as the basis for a sales contract.

Capacitance-type moisture meters are not restricted to the moisture-content range of resistance instruments, because the electrical capacitance of wood varies directly with the amount of moisture it contains, from the green to the oven-dry state. Further, the effect of temperature is so small as to be of no importance for ordinary purposes, and different species do not introduce variations in the measured moisture contents. The apparent advantages of the capacitance-type meters are, however, more than offset by this important disadvantage: the instruments measure the weight of water in wood, which can only be converted to a moisture content if the specific gravity of the wood is known. In practice, capacitance-type meters are calibrated on the average specific gravity of a species, which may well not be the actual specific gravity of the piece being tested for moisture content. Contact with the wood is made by various

types of suitably insulated condenser plates; in one form two plates are placed on opposite sides of the piece of wood under test, and in another four quadrant-shaped plates, assembled in the form of a flat circular disk several inches in diameter, are pressed against one surface only of the wood; the latter arrangement is used with capacitance-type meters in commercial production in America.

THE OCCURRENCE OF WATER IN TIMBER

It has been mentioned that the cells of wood are hollow, and that in the living tree many of the cell cavities are filled with water. Moreover, the solid material of which the cell walls are composed is itself saturated with water, much in the same way as seaweed that has just been uncovered by the tide. As might be expected, the "free" water in the cell cavities has very little influence on the properties of wood other than its weight; it may be compared with water in a bottle. If the "free" water were removed from the cavities of the wood the properties of the timber would not be greatly changed, any more than are those of a bottle emptied of its contents. It is actually impossible to remove all the water in the cell cavities without removing some from the cell walls, but, as a starting-point of our discussion, it is convenient to imagine the theoretical state when the cavities are empty and the cell walls are saturated; this state is known as the fibre saturation point.

In describing the cell-wall structure of woody tissue it was explained that the walls consist of several concentric layers, and that the layers are composed of fibrils, which were pictured as minute, needle-like units. The water in the cell walls appears to be in films between these units, more or less like mortar in a brick wall, but also inside the fibrils themselves, in some form of physico-chemical composition with the molecular structure of cell-wall substance. There is a limit to the thickness of the films of the water, and consequently to the amount of water held in the cell walls. In most timbers the walls can hold about 25 to 30 per cent. of their dry weight; when this amount is present the wood is at fibre saturation point.

Reverting to the analogy between seaweed and wood, it may be recalled that the former is sometimes used as a weather guide

because it is hygroscopic; that is, it is able to absorb moisture from a humid or damp atmosphere, and allows water to evaporate when the atmosphere is dry. Wood behaves in a similar way, in that there is a constant interchange of water between wood and air depending on which is the wetter. When "green" wood is exposed to dry air it loses water to that air. Free water in the cell cavities is first given up, and, when this has been removed,

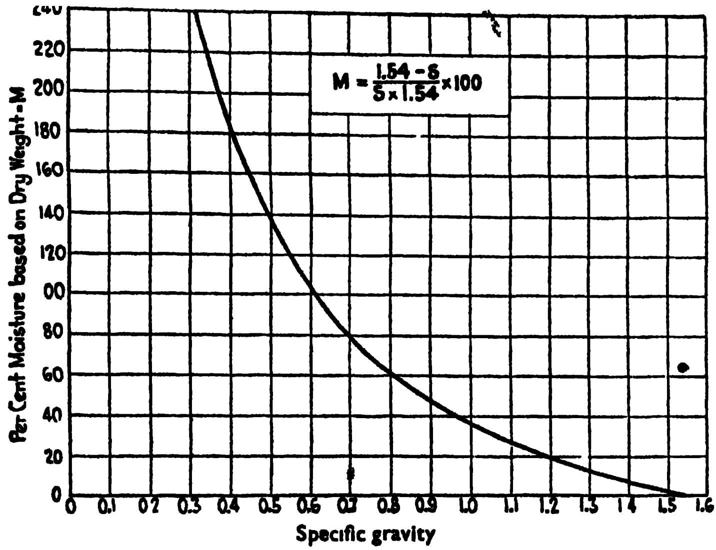


FIG. 16.—Relation between specific gravity and theoretical maximum moisture content. For explanation see text

By courtesy of A. Koehler, Esq

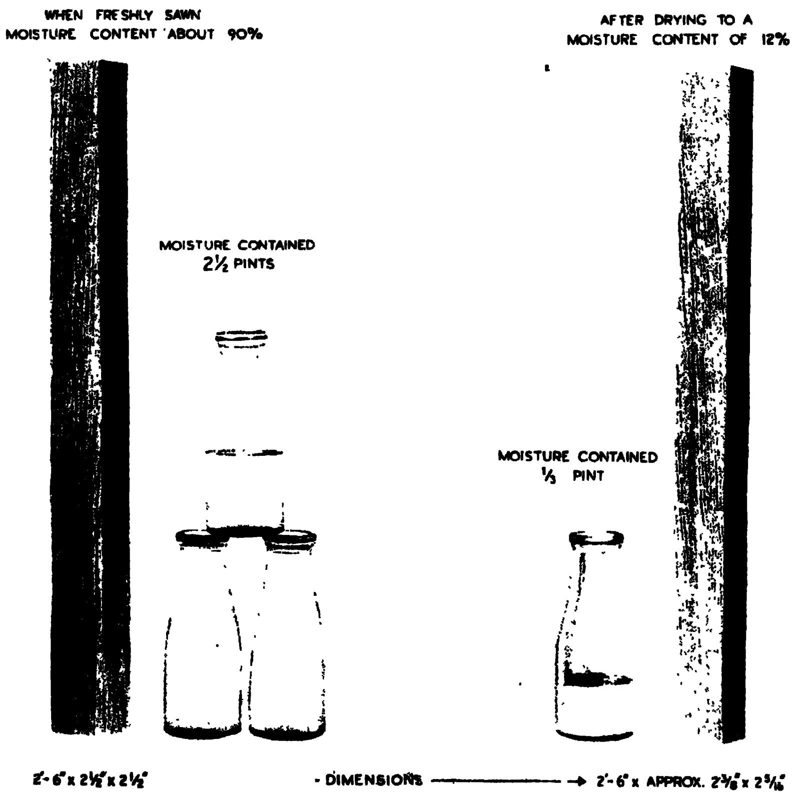
water in the cell walls is gradually absorbed by the surrounding air. The cell-wall water is conveniently termed **hygroscopic moisture.** With loss of water from the cell walls, wood shrinks, and, like seaweed, becomes stiffer and harder. If dry wood is placed in a humid atmosphere it absorbs water, and swells, and as it does so it becomes less rigid.

The amount of free water that a piece of wood can retain is governed by the volume of the cell cavities and intercellular spaces. The volume of these depends on the amount of cell-wall substance in any given volume of wood: the greater the proportion of wall substance, the greater the amount of water that can be absorbed by it, but the smaller the proportion of free water, and also of the total amount of water in a given piece of saturated

PLATE 38

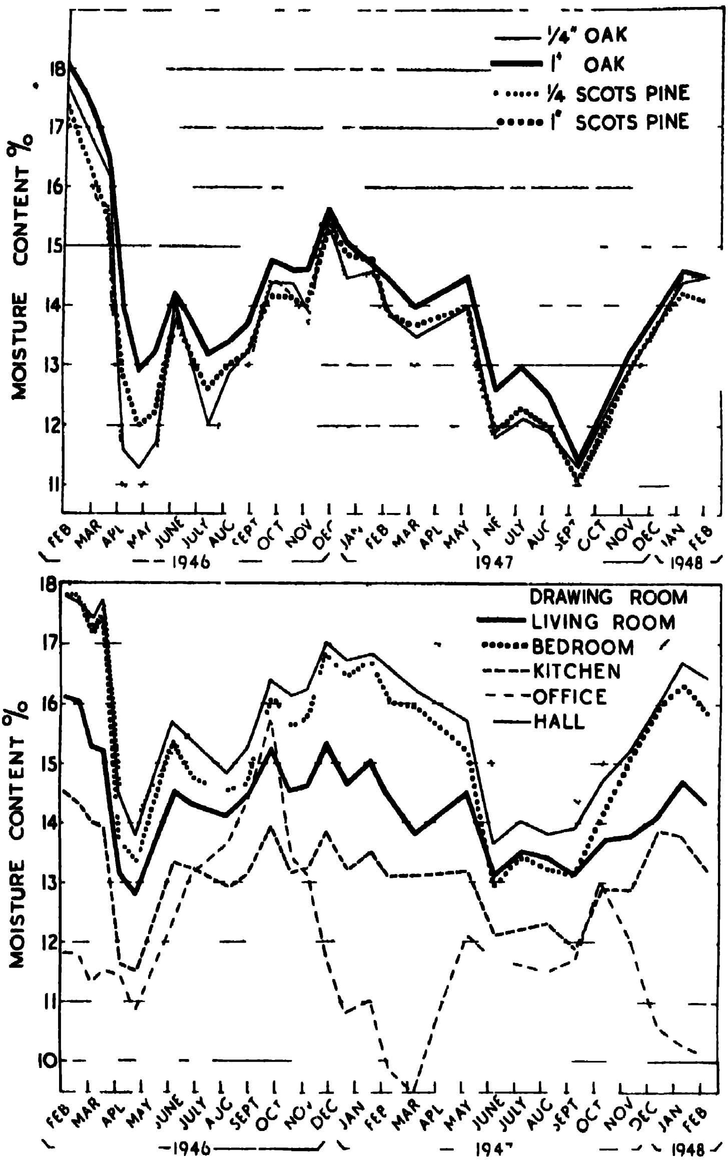
MOISTURE IN WOOD

MOISTURE CONTAINED IN AN OAK FURNITURE SQUARE



By courtesy of the Director, F.P.R.L., Princes Risborough

PLATE 39



Seasonal variation in moisture content of Oak and Scots pine samples kept in various environments in Princes Risborough February 1946 to February 1948

wood. This relation is illustrated theoretically by the curve in Fig. 16. The graph is only approximate, because infiltrates of different specific gravity from wood substance influence the position. The presence of infiltrates of higher specific gravity than wood substance causes the percentage of water read from the graph to be too low and the presence of those of lower specific gravity causes the percentage to be too high.

"MOVEMENT" IN WOOD

The tendency of wood to shrink or swell with changes in the moisture content of the atmosphere is a factor inseparable from the material. This characteristic behaviour of timber is popularly called "working" or "movement"; it cannot be eliminated by any particular method of seasoning or storage, although the deleterious results can be minimized by taking certain precautions. Certain chemical treatments, developed in recent years, hold out promise of modifying the hygroscopic properties of wood, thereby permanently reducing movement in service of such treated timber. These measures are discussed later in this chapter.

It is a matter of general observation that timber shrinks hardly at all along the grain: in drying from the green to the oven-dry condition the shrinkage in this direction amounts to only a few tenths of 1 per cent. In the radial and tangential directions, however, movement is appreciable, and in drying from the green to the oven-dry condition shrinkage in the radial direction may amount to 7 per cent., and in the tangential to as much as 14 per cent., and average figures for many timbers are 4 and 8 per cent. respectively. The movement occurring under ordinary atmospheric conditions is, of course, much less than occurs over the wide range from the green to the oven-dry state.

Tangential shrinkage is usually about twice as great as the radial, although in some species it may be as much as eight times as great. It will be appreciated that this difference is a matter of importance in the utilization of timber, and the differential shrinkage, as the ratio of tangential to radial shrinkage is called, may determine the suitability of a timber for a particular purpose. Advantage is commonly taken of the fact that quarter-sawn material of most timbers shrinks appreciably less than flat-sawn, *e.g.*, for flooring. The exceptionally low differential shrinkage of

Central American mahogany, coupled with the low total shrinkage of this wood, makes it particularly suitable for certain special purposes, *e.g.*, cabinet work and backing for engravers' plates. Differential shrinkage is important because it is related to distortion in drying, but low total shrinkage, and, particularly, a low absolute difference between radial and tangential shrinkage, largely determines the amount of movement in seasoned timber, and may in some circumstances be the more important factor, *e.g.*, in joinery and roofing shingles. Exceptionally low shrinkage characterizes certain softwoods, which have in consequence established reputations as joinery timbers, *e.g.*, yellow pine and western red cedar. Total shrinkage in hardwoods is typically greater than in softwoods, but an outstanding exception is teak, the total shrinkage of which is little higher than in the best softwoods. This fact, although the least stressed when the merits of teak are discussed, is one of the most pertinent reasons for the pre-eminent position of teak for so many exacting purposes.

Even more remarkable than teak, or Central American mahogany, is the East African muninga (*Pterocarpus angolensis* D.C.): the shrinkage of this wood is the lowest of any timber so far tested, being only 0·8 per cent. radially, and 0·9 cent. tangentially, in drying from the "green" state to 12 per cent. moisture content. Other timbers with a small overall shrinkage, and a low ratio of radial to tangential shrinkage, and therefore comparable in stability with teak, are afzelia (*Afzelia* spp.), iroko, and afrormosia (*Afrormosia* sp.).

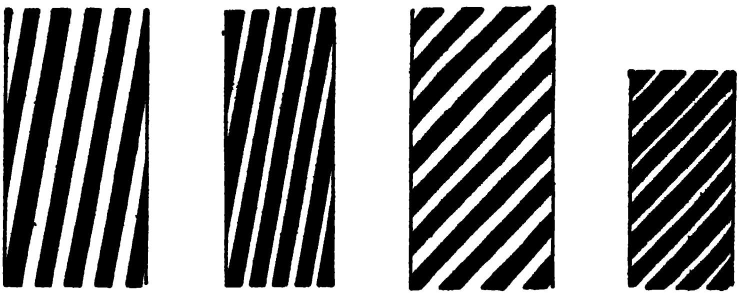
The fibrillar structure of the cell wall helps us to explain why longitudinal shrinkage is negligible, but transverse shrinkage is appreciable. Cell-wall moisture is held between the fibrils, and between the micellae that compose them, and removal of hygroscopic moisture results in these units packing closer together, causing appreciable contraction transversely, but little change in their length. It has already been mentioned that the fibrils are arranged more or less parallel with the longitudinal axis of the cell; they are not completely longitudinal, and any deviation, however slight, gives rise to shrinkage in the longitudinal direction as may be seen from Fig. 17.

The foregoing is a simplification of the facts, imperfectly though they are understood to date. The picture as presented does, however, assist in explaining certain readily observable phenomena:

a truly rectangular scantling of green wood is likely to become distorted in seasoning (Plate 37, fig. 2A), a flat-sawn board is liable to cup (Plate 37, fig. 2B), but a quarter-sawn board will remain flat (Plate 37, fig. 2C).

PERMANENT SET

But for differential shrinkage there would be no distortion of converted timber in drying: shrinkage would be the same in all directions, and each piece would merely become proportionately smaller. On the other hand, the true geometrical shapes that



(i) (ii) (iii) (iv)

FIG 17 —Fibrillar structure and its relation to shrinkage. (i) Diagrammatic representation of fibrillar structure in green timber the black lines represent the fibrils and the white the films of water, (ii) the same cell when seasoned the black lines are slightly narrower as a result of small water losses from the films surrounding the fusiform bodies, but the white lines are appreciably narrower because of the much larger water-losses from the films surrounding the fibrils (note that the reduction in length of the cell is much less than the reduction in width), (iii) and (iv) diagrammatic representation of fibrillar structure in green and air dry timbers, in which the pitch of the fibrils is less than in normal wood (note that the reduction in length of the cell as the wall dries out is much greater than in normal wood)

differential shrinkage call for are usually not attained in practice, because of the influence of drying stresses, and the peculiar property of wood substance of becoming set.

When wood dries under a compressive stress it assumes a compression set; that is, its final dimensions are less than they would be were it dried under stress-free conditions. The final dimensions are permanent for the particular combination of humidity and temperature conditions of the atmosphere of the moment. Hence the term permanent set. Subsequent changes in the prevailing atmospheric conditions will be accompanied by shrinkage or swelling of permanently set wood, as in stress-free wood, but the starting-point of the dimensional changes is that

of the set condition. Because converted timber rarely dries uniformly throughout, stress-set timber is almost the rule rather than the exception, and this upsets the predictable final dimensions that differential shrinkage alone requires. Wood can also dry under a tensile stress, when the final dimensions are greater than they would be under stress-free conditions, *i.e.*, tension set has been induced.

Ordinary re-wetting, or further drying, of compression or tension set wood does not relieve the set condition; high temperature treatments in a saturated atmosphere, *i.e.*, steaming, alone will remove permanent set. This is because the stresses that induce set are appreciable: the individual elements or cells are themselves distorted, as is revealed by microscopic examination.

Set does not arise only in the course of drying green timber, that is, in seasoning; it can occur in timber in service. For example, adequately seasoned flooring, laid in a new building that has not dried out fully, tends to pick up moisture from its surroundings and swell. If the floor has been clamped up tightly it will be restrained from swelling the full amount, and, in consequence, compression set results. As the building dries so will the flooring, but, starting from the set state, the flooring ultimately reaches equilibrium (its initially intended state) with smaller dimensions than its initial dimensions. For similar reasons, wood adequately seasoned for the service conditions to which it will be exposed, and without provision for " movement ", is liable to shrink to a noticeable extent over a period of years. This explains why provision for " movement " should always be made in floors, for example, whatever precautions are taken to season wood adequately in the first place. Compression set is also induced in ladder rungs or axe handles if they are allowed to become wetted: on drying, previously tight-fitting rungs or handles are found to be loose (see also Plate 37, fig. 2).

Variation in the amount of shrinkage (or swelling) in timbers of different species is not explained by the foregoing discussion. The small shrinkage in the radial direction has been attributed to the restraining influence of the rays, and recent critical studies have added further explanation by reference to the microstructure of the cell wall. Ritter and Mitchell [1] have sought

an explanation in the fibrillar structure of the wall. Pits are more numerous in the radial walls of fibres than in the tangential walls, and pits must cause a displacement of the fibrils, much as the elements of the main stem are displaced by knots. In consequence, the influence of longitudinal alignment of the molecular structure making up the fibrils comes into play, and because this component is introduced more frequently in the radial than in the tangential plane, by reason of the more numerous pits, total shrinkage in drying is less in the radial than in the tangential direction.[1]

ESTIMATION OF MOISTURE CONTENT FROM MEASUREMENT OF SHRINKAGE

The methods of determining moisture contents that have already been described do not demand especially elaborate apparatus, nor appreciable technical skill, but they are suitable only where moisture-content determinations are a routine practice, as they should be in timber yards, joinery works, and other wood-using factories generally. A simple test is available for checking the moisture content of timber without the use of special apparatus; it is based on measurement of shrinkage, and is useful in determining the suitability, as far as seasoning is concerned, of timber on a job.

The procedure is to select a representative scantling, and one that has not been lying on top of the pile, and to cut off a cross section, about ½ in. along the grain, some 2 feet from one end. Measure the width and thickness of the sample accurately to the nearest sixty-fourth of an inch. To ensure re-measurement in precisely the same line, it is advisable to put small dots at the points of measurement. Expose the sample in a well-ventilated, inhabited room for a few days, *i.e.*, 4 to 7 days, and then re-measure. In this period the sample should reach equilibrium with its surroundings, and the decrease in width and thickness will represent the amount of shrinkage that will occur when the timber is put into service. If this test is carried out in summer, greater shrinkage than that actually measured may be expected to occur in winter, because domestic heating dries the air more than do summer temperatures. It is possible to obtain an idea

[1] See further discussion of this subject in Appendix I.

of the amount of shrinkage to be expected without the necessity of measurement, by matching the test sample from time to time with the identical piece of timber from which it was cut. Measurement is more satisfactory, however, and more convenient when the timber to be tested is some distance from the office where the experiment is carried out.

This test gives information as to the state of the timber at the time of inspection. If there is a considerable delay between the time of test, and the time when the timber is put into use, a loss, or increase, of moisture may occur in the stack in the interval, *i.e.*, further seasoning may occur, or, if the timber was kiln-seasoned stock, it may become wetter. Little change is likely to take place in a period of 3 or 4 weeks if the timber is close piled and covered with a tarpaulin, but if the timber is properly stacked and roofed over, some drying (down to 15 or 16 per cent.) of partially seasoned stock may occur during such a period in the summer months. Little or no drying, even under the most favourable conditions, is likely to occur out-of-doors in winter. Timber of low moisture content will absorb moisture while awaiting fixing: up to about 15 to 16 per cent. in summer, and up to 18 to 20 per cent. in winter, if protected from the weather, but if exposed to rain the figures quoted may be exceeded in a short space of time.

VARIATION IN MOISTURE CONTENT OF GREEN TIMBER

The amount of moisture in timber of living trees and newly felled logs is primarily a question of species; in some it is only about 40 per cent., and in others it may exceed 200 per cent. of the dry weight. In Douglas fir, for example, the average moisture content of newly felled trees is about 40 per cent., but in the American chestnut it exceeds 120 per cent. In most species there is usually a marked difference in the moisture content of sapwood and heartwood; particularly is this the case with softwoods. In long-leaf pitch pine, for example, the moisture content of the sapwood exceeds 100 per cent., and the heartwood ranges from 30 to 40 per cent. Moisture content may also vary with height in the tree: butt logs of sequoia and western red cedar often sink in water, although the upper logs float. In species with a marked

difference between the moisture content of sapwood and heartwood the position may, however, be reversed, because the upper logs contain a higher percentage of sapwood of high moisture content.

There is no evidence in support of the widely held opinion that timber felled in winter, when the sap is said to be "down", is drier than that felled in summer, when the sap is said to be "up". In fact, such evidence as is available suggests that there is either no difference, or the moisture content is, if anything, somewhat higher in the winter months. In Germany figures have been collected for birch, poplar, and oak, showing that the moisture content of these timbers was lower between June and February than between February and June, the minimum occurring in June or July and the maximum in March, April, or June. Similar figures have been collected for several species in America, and in no case was the moisture content in winter found to be lower than that in summer. In the light of these figures the prejudice against summer felling cannot be sustained on the grounds usually advanced. There is some justification on scientific grounds, however, for preferring winter felling. Chief of these is the reduced activity of insects and fungi during the cool months, and the lower degrade in seasoning resulting from a slowing down of drying from the ends of logs. Moreover, the risk of damage to the bole is probably greater when felling heavy-crowned trees in full leaf. The prejudice no doubt arose, partly as a result of practical experience, which showed that winter felling gave better results, and partly because of economic necessity: agricultural activities absorbed the population in the summer months and left them free for work in the woods during winter.

VARIATION IN MOISTURE CONTENT OF SEASONED TIMBER

Considerable variation in moisture content occurs in different pieces of so-called "air-dry" or "seasoned" timber. The moisture content at any given moment will depend on the atmospheric conditions to which the timber is exposed, the stage reached in the drying process, the dimensions of the piece, and the species.

However prolonged the period, or favourable the conditions,

drying does not continue indefinitely: a stage is reached when there is no further interchange of moisture between the wood and air; this may be referred to as a state of equilibrium. Any subsequent change in temperature, or increase or decrease in moisture in the air, however, upsets this balance, and there is a further exchange of moisture until a new state of equilibrium is reached. This interchange occurs because the amount of available water is distributed between air and wood in certain definite proportions when equilibrium conditions are established; *i.e.*, both air and wood have affinities for water, and mutual adjustment is made when both are subjected to stable conditions of temperature and available water supplies for a sufficiently long period.

Much of the so-called "seasoned" timber on the market today is little more than surface dry, and must be expected to shrink appreciably until it eventually comes into equilibrium with ordinary, atmospheric conditions. Timber in old houses and furniture, on the other hand, has already reached the equilibrium state and is, therefore, relatively stable. If, however, the atmospheric conditions are changed, as, for example, by the installation of central heating in a previously unit-heated house, the moisture equilibrium will be disturbed and noticeable movement will occur in the timber. A case is known of genuine Stuart pine panelling that had been in position for 300 years shrinking when re-erected in a centrally-heated room. More recently the installation of air-conditioning plants in buildings has introduced new seasoning problems, particularly in the tropics: if the moisture-equilibrium conditions are changed, and, in practice, they always are, shrinkage or swelling will occur in furniture, fittings, and joinery, previously in equilibrium with ordinary atmospheric conditions. In extreme circumstances, such as those prevailing in the tropics, the difference in the average equilibrium moisture contents of timber in ordinary and air-conditioned buildings may be as high as 5 per cent., *e.g.*, from around 15 per cent. to as low as 10 per cent., and furniture, etc., that was previously stable is bound to shrink appreciably, and probably develop serious splits, under the new conditions. If kiln-seasoning facilities are available it is a simple matter to dry timber to any required moisture content, when, provided the wood is not exposed to higher moisture-equilibrium conditions

for too long a period in the course of manufacture, it will remain stable under the low moisture-equilibrium conditions to which it was kiln-dried. If timber below atmospheric moisture-equilibrium conditions is required, and kiln-drying facilities are not available, the conditioned chamber in which the timber is to be installed should be used as a kiln. Before the wood required for furniture, fittings, and interior finish for the conditioned room

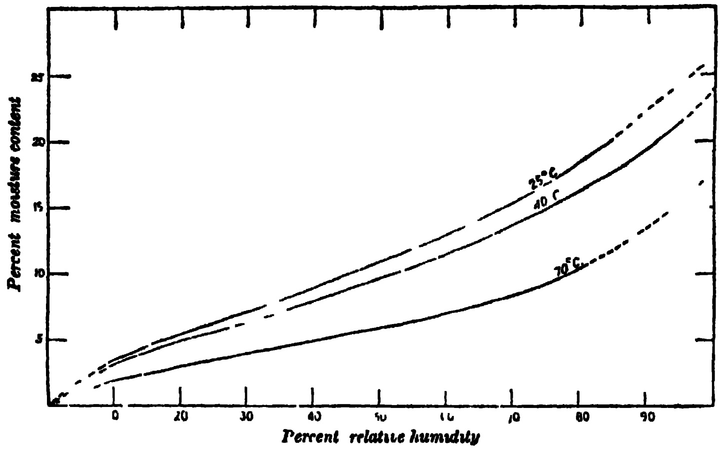


FIG. 18 —Curves showing equilibrium moisture contents for different relative humidities at 25°, 40°, and 70° Centigrade

By courtesy of the Director, F P R L, Princes Risborough

is made up, it should be thoroughly air-dried and then re-stacked in the conditioned chamber, with the plant running, until the required low equilibrium moisture-content conditions are obtained, when shrinkage and splitting after manufacture will be avoided.

The moisture content of air-seasoned timber, at any given temperature and in equilibrium with its surroundings, bears a direct relation to the relative humidity of the atmosphere. Atmospheric air normally contains some water vapour: for every temperature there is a definite maximum amount of water vapour that air can hold. When the maximum amount is reached the air is said to be saturated. The relative humidity of the air is the actual amount of water vapour present at any time, expressed as a percentage of the maximum possible for that temperature. The curves in Fig. 18 show the relation between the moisture content of wood and the relative humidity of air during drying, at three different temperatures. From these

curves the moisture content of timber in equilibrium with its surroundings can be read for any particular relative humidity, at temperatures of 25°, 40°, and 70° C. Separate curves for any other temperatures could be constructed; they would follow similar trends to those illustrated. The curves illustrated are average figures for several timbers. The curves for one timber, at these and other temperatures, although following the same

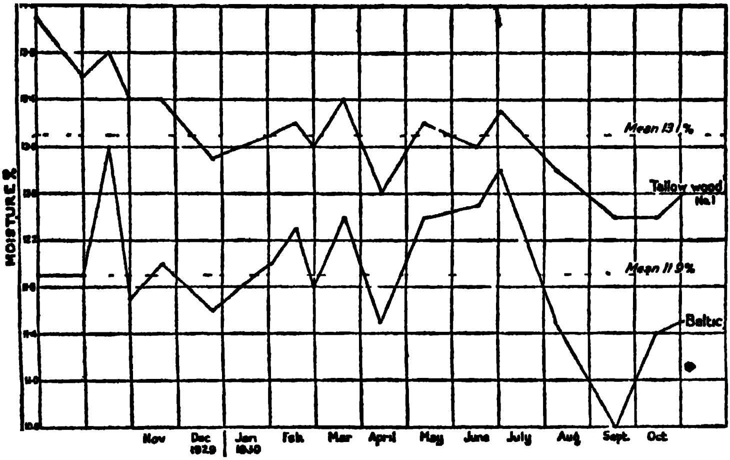


FIG. 19 —Graph showing variation in the moisture content of tallow wood and Baltic deal, *i.e.*, European redwood

By courtesy of M B Welch, Esq, and reproduced from the Journ Royal Soc of New South Wales

general trend, would not be absolutely identical, because the equilibrium moisture contents of different timbers for any given set of atmospheric conditions are not the same. For example, the equilibrium moisture content of teak exposed to air at 40° C. and 70 per cent. relative humidity is just under 11 per cent., whereas oak exposed to the same temperature/humidity conditions would reach equilibrium at a little over 14 per cent moisture content. These two timbers provide examples of the extreme range in equilibrium moisture contents, probably with many more timbers approaching the figures for oak, rather than those for teak. In effect, teak, and other similar timbers, are less hygroscopic than most woods, which explains their greater stability in use.

The drying curves discussed in the previous paragraph do not represent the position when the process is reversed, and

dry wood is gaining moisture from the atmosphere. In such circumstances the actual moisture content, when a new state of equilibrium is reached, is very slightly lower than would be the case if the timber had not previously been dried below this level.

A study of the variation in moisture content of seasoned timber with changes in the relative humidity over a period of fifteen months was made in Australia several years ago. Twenty-six examples, of eleven species, were selected for this purpose. The variations were found to agree closely in the different samples, although the actual equilibrium moisture contents for each species were different. Fig. 19 illustrates the amount of variation observed in two timbers over the period, and it is well to remember that variations of this order occur in seasoned timber in service in every locality.

Similar studies were made by the officers of the Seasoning Section of the Forest Products Research Laboratory, Princes Risborough, before the last war, and repeated subsequently to ascertain whether the restricted use of fuel today is influencing equilibrium moisture contents of timber in service. Test pieces of oak and Scots pine were used for the investigation, and were exposed in different rooms of four houses at Princes Risborough, and in a centrally-heated office at the laboratory. As is to be expected, maximum moisture contents occurred in the winter months in samples exposed in houses not centrally heated, and minimum moisture contents in the summer months, whereas in the centrally-heated office the periods of maximum and minimum moisture contents were reversed; Plate 39 illustrates the seasonal moisture content readings obtained from these investigations. It will be seen that the differences in moisture content at different periods were appreciable, and, further, that the changes in moisture content were not haphazard, but followed a remarkably similar pattern in all the experiments, irrespective of species of timber used or the precise locality where the samples were exposed, showing that prevailing atmospheric conditions were the over-riding factor in determining moisture movements. The figures for the oak samples were consistently about ½ per cent. higher than those for Scots pine in identical circumstances.

Shrinkage and swelling result, of course, from changes in moisture content, but subsequent movement is minimized by selecting in the first place material of a moisture content midway

in the range to be expected in service. A series of standards for different purposes, which it is recommended should be adopted in this country, has been worked out at the Forest Products Research Laboratory, Princes Risborough (Tables II and III. This is also shown diagrammatically in Fig. 22).

TABLE II

MOISTURE-CONTENT SPECIFICATIONS FOR CONSTRUCTIONAL TIMBERS IN GREAT BRITAIN[1]

Timber for	Moisture content not to exceed
	Per cent.
General carpenter's work	25
High-class carpenter's work	20
General joinery work	15
Best joinery, block and strip flooring, panelling, and decorative work	9 to 12* 10 to 14†

* For centrally-heated rooms and buildings.
† For rooms and buildings not centrally heated.

Similar figures to suit American conditions have been issued by the U.S. Department of Agriculture. For interior-finish wood-work in dwellings in most parts of the United States a moisture content of 5 to 10 per cent. is recommended, but in the damp

TABLE III

MOISTURE-CONTENT SPECIFICATIONS FOR FURNITURE TIMBERS IN GREAT BRITAIN[2]

Timber	Environment			Average conditions
	Bedroom	Living-room	Office	
	Per cent	Per cent	Per cent	Per cent.
Oak (American white) . .	13·6	12·8	12·5	13
Mahogany (Cent. American) .	12·8	12·0	11·8	12·3
Scots pine	12·2	11·3	11·2	11·5

southern coastal regions a range of 8 to 13 per cent. is suggested, and in the dry southern regions 4 to 9 per cent. For exterior sheeting, framing, siding, and exterior trim, the corresponding figures are 9 to 12 per cent. in the first two regions and 7 to 12 per cent. in the third.

[1] Figures from Report of the F.P.R. Board for the year 1930, by courtesy of the Director, F.P.R.L., Princes Risborough.

[2] Figures from *The moisture content of wood with special reference to furniture manufacture*, Bull. No. 5, 1929, by courtesy of the Director, F.P.R.L., Princes Risborough.

In the United Kingdom, and most regions of the United States, thoroughly air-dry timber, seasoned under the most favourable conditions, contains 15 to 18 per cent. of moisture; in the more humid tropics, *e.g.*, Malaya, 14 to 18 per cent.; and in hot arid regions 8 to 12 per cent. or even less.

The rapidity with which adjustments to changes in the relative humidity of the atmosphere occur depends on the dimensions of the timber and on the difference between the initial, and equilibrium, moisture contents of wood. The adjustment is more rapid when the difference is large, and becomes extremely slow as equilibrium conditions are approached. But for this, movement in timber would be greater and more frequent than it is.

The equilibrium moisture contents cited in the tables are mean figures for timber in inhabited buildings, and a deviation of ± 2 per cent. from these figures in individual pieces would be unlikely to have serious practical consequences. Special precautions, however, are necessary when installing wood-work in new buildings; it is not sufficient merely to select timber of the correct moisture content for subsequent conditions. Immediately on completion, the relative humidity of the air in new buildings is likely to be abnormally high, and timber in equilibrium with such atmospheric conditions would reach equilibrium at a moisture content of between 16 and 20 per cent., according to the season. If joinery and finishings of 10 to 12 per cent. moisture content are installed in these circumstances some swelling, which might give rise to buckling, is to be expected. On the other hand, it would not do to use timber of 16 to 20 per cent. moisture content, because appreciable shrinkage would occur later. Two alternative courses are to be recommended . either temporary heating should be installed, and the building dried out before the joinery and finishings are fixed, or fixing should be delayed for three to six months to give the building a reasonable opportunity of drying out on its own accord. The risk of introducing compression set in timber dried to the correct final moisture content before fixing must not be overlooked (see pages 93 and 94).

The practice of baking buildings in the early days of occupation is thoroughly unsound, and may result in considerable damage to the timber, because even the most carefully seasoned and fitted joinery will shrink and distort if suddenly exposed to much drier conditions than those for which it was prepared. The proper

course is to employ no more heat than is necessary for occupational use, and this applies both before and after the joinery is fixed. Pre-baking is likely to give trouble with the carcassing timber and lath-plaster work.

Size, density, species, and initial moisture content of the timber, and rate of air circulation and its temperature, are, then, the factors that influence the rate of adjustment of the moisture in wood to the relative humidity of air. It may also be mentioned that flat-sawn material will lose moisture more rapidly than quarter-sawn, and sapwood more rapidly than heartwood.

FACTORS AFFECTING THE HYGROSCOPICITY OF WOOD

We have seen that the hygroscopic nature of wood is responsible for causing variations in moisture content of timber follow changes in the relative humidity of the atmosphere Further it has been mentioned that hygroscopicity cannot be

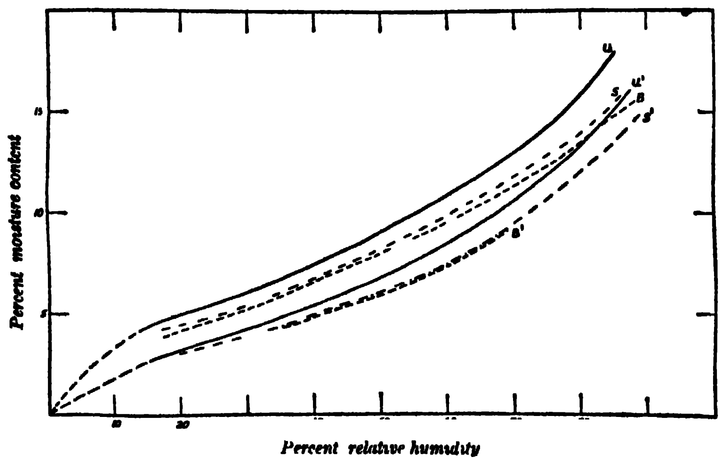


FIG. 20.—Curves showing effect of boiling and steaming on the hygroscopicity of wood U = untreated, U¹ = the same, but absorbing moisture from the dry conditions; S = steamed, S¹ = steamed wood absorbing moisture from the dry state; B = boiled, B¹ = boiled wood absorbing moisture from the dry state

By courtesy of the Director, F.P R L, Princes Risborough

eliminated: it can, however, be permanently reduced by certain treatments. A permanent reduction in the hygroscopic properties of wood is effected by high-temperature treatments, steaming, boiling, and certain chemical means. The higher the temperature,

and the longer it is maintained, the more is hygroscopicity reduced, but too severe treatments may damage the timber. Boiling and steaming act similarly, as may be seen from the curves in Fig. 20.

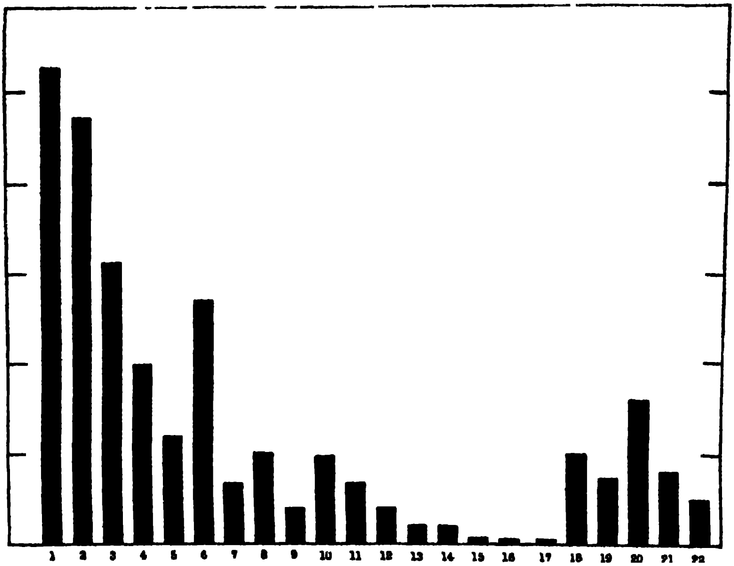


FIG. 21.—Relative effectiveness of protective coatings against moisture absorption by dry wood exposed to a saturated atmosphere for 17 days*

1. Untreated wood.
2. Five coats linseed oil, 2 coats wax.
3. Impregnation with paraffin and gasoline (vacuum and pressure).
4. Cellulose varnish (vacuum and pressure).
5. Three coats of cellulose varnish.
6. Filler and 3 coats spar varnish. (Poorest of 43 tested.)
7. Filler and 3 coats of spar varnish. (Best of 43 tested.)
8. Filler and 2 coats of enamel (red-lead pigment) plus varnish.
9. Filler and 2 coats of enamel (white-lead pigment) plus varnish.
10. Filler and 3 coats commercial enamel (average of 11 brands).
11. Filler and 3 coats commercial enamel (best brand).
12. Filler and 3 coats of shellac and aluminium powder.
13. Five coats of bakelite plus 5 coats of varnish.
14. Metal leaf coatings: filler and shellac or varnish under-coat and varnish size and aluminium leaf and 2 coats of varnish shellac or enamel (average of all types).
15. Ditto (best type).
16. Sprayed with copper or aluminium and 3 coats of varnish.
17. Electroplated with copper.
18. Filler and 3 coats, brushed. (Average of 7 varnishes.)
19. Filler and 3 coats, dipped. (Average of the same 7 varnishes.)
20. Filler and 2 brush coats.
21. Filler and 6 brush coats.
22. Filler and 12 brush coats.

* From A. Koehler, *The structure, properties and uses of wood*, by courtesy of the author.

The solid lines are drying curves for untreated wood, and the dotted ones are those for timber that has been either steamed or boiled. Boiling will be seen to be more effective than steaming.

It is not known how the hygroscopic properties are permanently

altered by the boiling and steaming, and, in practice, it does not matter whether there is an actual reduction so long as subsequent movement is reduced. Paints, varnishes, and linseed oil, for example, are effective because they reduce the rate at which moisture can be absorbed by timber: as a result of their semi-permeable nature they offer resistance to the exchange of moisture between the air and wood. Fig. 21 illustrates the relative effectiveness of several different protective coatings. It will be seen that the selection of a suitable paint or varnish is an important matter, and can be very effective in reducing movement in timber. Of several different protective coatings tried, aluminium leaf, between a filler and shellac under-coat and two coats of varnish or enamel, was the most efficient. Varnishes, enamels, and paints containing aluminium powder, were less effective, but considerably more efficient than ordinary paints; and linseed oil, and wax had little effect at all. Protective coatings in no way change the hygroscopic properties of wood.

Two other methods of controlling movement in wood have been attempted, namely the introduction of hygroscopic substances to change the equilibrium moisture content, and the introduction of materials to occupy the space that would normally be held by the sorbed moisture. It will be realized that the first method naturally involved the second in some degree. Creosote and hot paraffin have been found to reduce hygroscopicity, and claims have been advanced that ozone and ammonia reduce shrinkage, but the effectiveness of the former has been questioned. Some substances (*e.g.*, caustic soda) increase hygroscopicity.

The substances most commonly used in moisture control in the past have been common salt, and sugar (Powell process). These are supposed to act partly by replacing the sorbed moisture, and partly by their influence on hygroscopicity. If it were possible to introduce sufficient quantities of such materials into wood, shrinkage (or working) would be eliminated; such heavy impregnations would, however, make the treated timber damp and unpleasant, and they would be difficult and expensive to achieve.

None of the methods for permanently reducing the hygroscopic properties of wood — as opposed to interposing a semi-impervious barrier between wood and the surrounding atmosphere — discussed in the foregoing paragraphs can be regarded

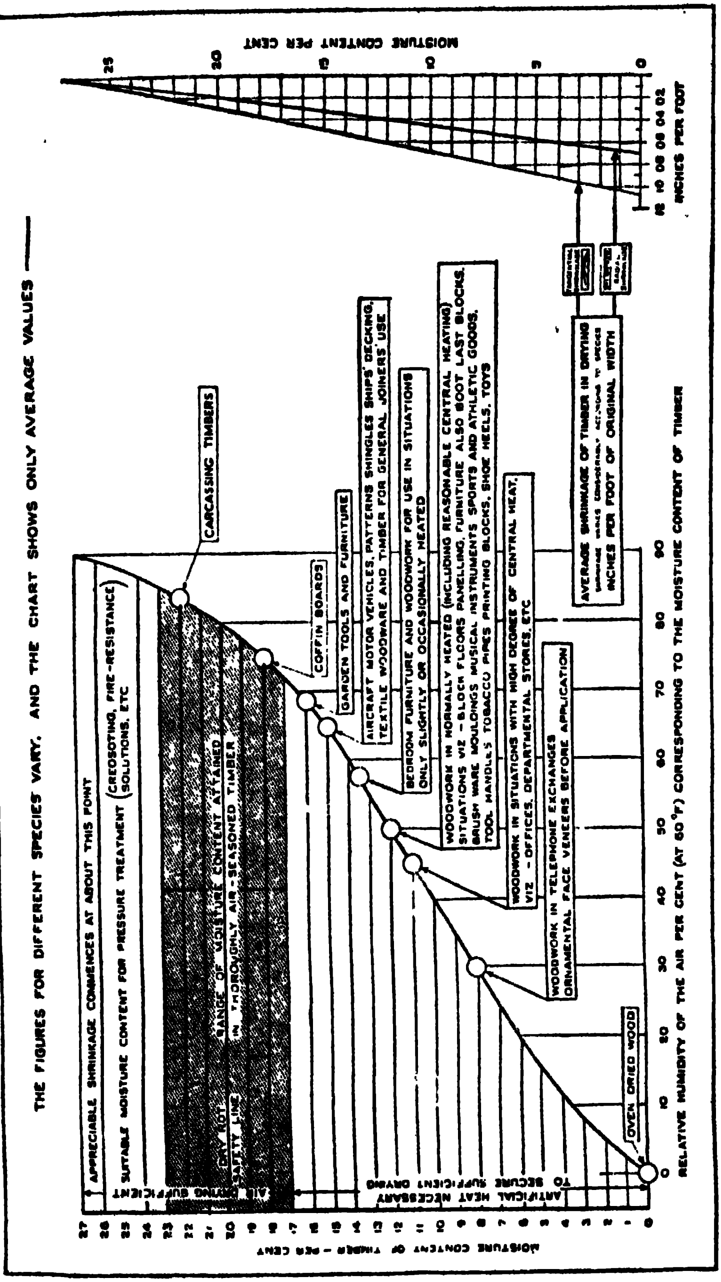


FIG. 22.—Moisture content of timber for different purposes

By courtesy of the Director, F.P.R.L., Princes Risborough

as effective commercial methods for reducing shrinkage, and subsequent movement of wood, to negligible proportions. More recently, the effectiveness of *impregnating* wood with waxes or with synthetic resins has been investigated. Waxes are effective in reducing shrinking and swelling over short periods, and they impart some other desirable properties to the wood, but they do not confer immunity from movement in wood exposed to moisture over long periods. Impregnation with resins appears to reduce hygroscopicity permanently, the resin entering the fine structure of the cell wall, being fixed there by polymerization under temperature. Polymerization is a chemical process by which molecules of certain organic compounds are induced to unite to form giant molecules. Modern plastics are examples of polymers. Impregnation with resin to the extent of 20 per cent. of the dry weight of the wood has been found to reduce hygroscopicity, as measured by subsequent shrinkage and swelling, by 50 to 75 per cent. Certain other properties are also enhanced, *e.g.*, side hardness, measured by resistance to indentation, has been increased by 50 per cent , and moisture transfusion has been reduced to 10 per cent. of that of untreated wood. Moisture transfusion is a convenient term for describing the property of absorbing moisture and transmitting moisture. A low value for moisture transfusion is indicative of suitable materials for use as moisture barriers: untreated wood is not suitable, but wood impregnated with synthetic resins is. The use of synthetic resins in this connection may be said to be still in the experimental stage, but some commercial processes have been patented. The scope of such treatments is very extensive, and their present relatively high cost should not discourage their full investigation. A development from mild treatments is the use of synthetic-resin products, with very high pressures, to give the so-called compressed wood that found special uses under war-time conditions. With such treatments the properties of the resultant material are very different from normal wood, or even lightly treated timber. Hardness and strength properties, for example, are enormously increased; in fact, an entirely new product results that cannot be compared on any basis with natural wood, but the amount of chemicals used and the cost of the treatment are naturally very high.

The officers of the Wood Preservation Section of the Forest

Products Research Laboratory, Princes Risborough, have experimented with the impregnation of wood with various natural oils and resins, in an endeavour to find cheaper products than the synthetic resins for modifying the hygroscopic properties of wood.[1] A treatment that has been developed from this work consists of impregnating wood with a solution of rosin in paraffin wax. Such impregnated wood was found to machine remarkably well, and the rate of moisture absorption was reduced, thereby tending to stabilize the dimensions of the treated wood. The method lends itself to ordinary commercial pressure-impregnation processes, whereby heavy impregnations can be obtained with such permeable woods as beech, hornbeam, lime, sycamore, and alder. Even rosin in paraffin wax is not particularly cheap when heavy impregnations are used, since, at 6d. per lb., a timber such as beech can take up as much as 12s. 6d. per cubic foot of these ingredients, but, for certain special uses of wood, the process is thought to have commercial possibilities.

CHAPTER VII

THE DENSITY OF WOOD

In Part II we discussed certain characters of wood, visible to the naked eye, that in some measure determine its usefulness and that are a guide to identification. In this chapter we will consider another character, namely the weight, which is the best single criterion of the strength of wood. It is usual to speak of the weight of wood in terms of a standard volume and this figure is called the **density**. In this country the density of wood is expressed in pounds per cubic foot, and, on the continent, in grams per cubic centimetre.

DETERMINATION OF DENSITY

Density is defined as the mass of unit volume, and is therefore obtained by dividing the weight by the volume. The weight is determined on a balance or pair of scales, to an accuracy depending on the purpose for which the determination is required. For most practical uses an accuracy of 2 per cent., *i.e.*, $\frac{1}{3}$ ounce in the pound, is adequate. There are several ways of determining the volume. The simplest is a calculation based on the direct measurement of length, width, and thickness, of a squared sample. It is recommended that the block should be not less than $3 \times 2 \times 1$ in. For smaller blocks, and those of irregular shape, the following procedure is more suitable. A beaker of water is placed on the pan or balance and counterbalanced by sand or weights. Then the test block, suspended by a needle clamped in a stand, is lowered into the beaker and completely immersed in the water; arrangements are made so that this can be done without any of the water running over, and so that when the block is immersed it is not in contact with the sides or bottom of the beaker. Weights are then added to the opposite pan until equilibrium is restored: the weights in grams added to restore balance are equal to the volume of the test block in

cubic centimetres. It is, of course, necessary to pay regard to the units in which measurements are made. If the weight of the block is in ounces the volume will be required in cubic feet. This can be arrived at from the immersion method if the weights added to restore balance are English units instead of grams, and a correction factor is used. The added weight, in ounces, multiplied by 0·001 gives the volume of the sample in cubic feet. As wood is a

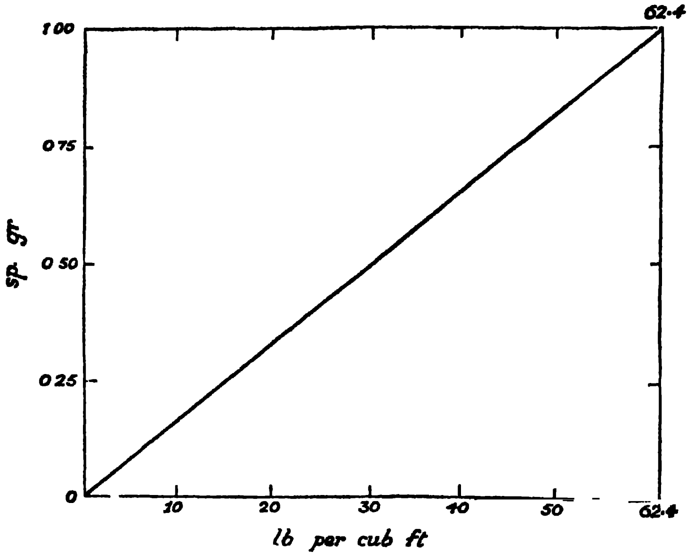


FIG. 23.—Specific gravity and pounds per cubic foot

porous substance it is necessary to coat the test block with an impervious material, such as paraffin wax, before immersion, unless the wood is still "green". The block is dipped in a bath of melted wax and quickly removed, and when the coating has set the surplus wax is scraped off.

The density is found by substitution in the formulae :

$$\text{(I)} \qquad \frac{\text{Weight of block in grams}}{\text{Weight in grams added to restore balance}}$$

$$\text{(II)} \qquad \frac{\text{Weight of block in lb.}}{\text{Weight in ounces added to restore balance} \times 0{\cdot}001}.$$

In (I) the density is obtained in grams per cubic centimetre and in (II) in pounds per cubic foot.

In practice, it will often be simpler to use the metric system for the actual density determination, and to convert this figure to pounds per cubic foot by means of a conversion factor or graph (Fig. 23). In effect, the **specific gravity** is determined, and the density is calculated from it. The specific gravity of a substance is merely the relative density of that substance in comparison with a standard density: usually that of pure water in grams per cubic centimetre. Water is a particularly useful standard because the weight of one cubic centimetre is one gram. In consequence, provided the weight of any given volume of water is known, the weight (or density) of the same volume of all other substances can be calculated from their specific gravities. For example, the weight of a cubic foot of water is 62·4 pounds, so that if we know the specific gravity of any wood, and multiply the figure by 62·4, we obtain its density in pounds per cubic foot.

VARIATION IN DENSITY OF WOOD

A piece of perfectly dry wood is composed of the solid material of the cell walls, and the cell cavities, which contain air and small quantities of gum and other substances. The specific gravity, or relative density, of the solid material of the walls has been found to be similar in all timbers, and is in the neighbourhood of 1·5; that is to say, the cell walls are about one and a half times as heavy as water, and a cubic foot of solid wood, without cell cavities and intercellular spaces, would weigh roughly 94 pounds. Different timbers, however, vary in weight from about 3, to as much as 83, pounds per cubic foot. This variation is caused by differences in the ratio of cell wall to air space in different timbers, and to the amount of water in the test piece at the time the density was determined; if it were possible to compress absolutely dry wood into a solid mass the maximum variation in density of different samples of all woods would probably not exceed 4 per cent.

Besides the range in density occurring in timbers of different species, there is a considerable variation in density between different samples of the same species, and containing the same amount of water, expressed as a percentage of the dry weight of wood in the sample (Figs. 24 and 25). This variation occurs between the timber of different trees, and in timber from different

parts of one tree. In the former, variation follows no particular pattern, but is influenced by such factors as rate of growth, site conditions, and probably other growth factors as yet not fully

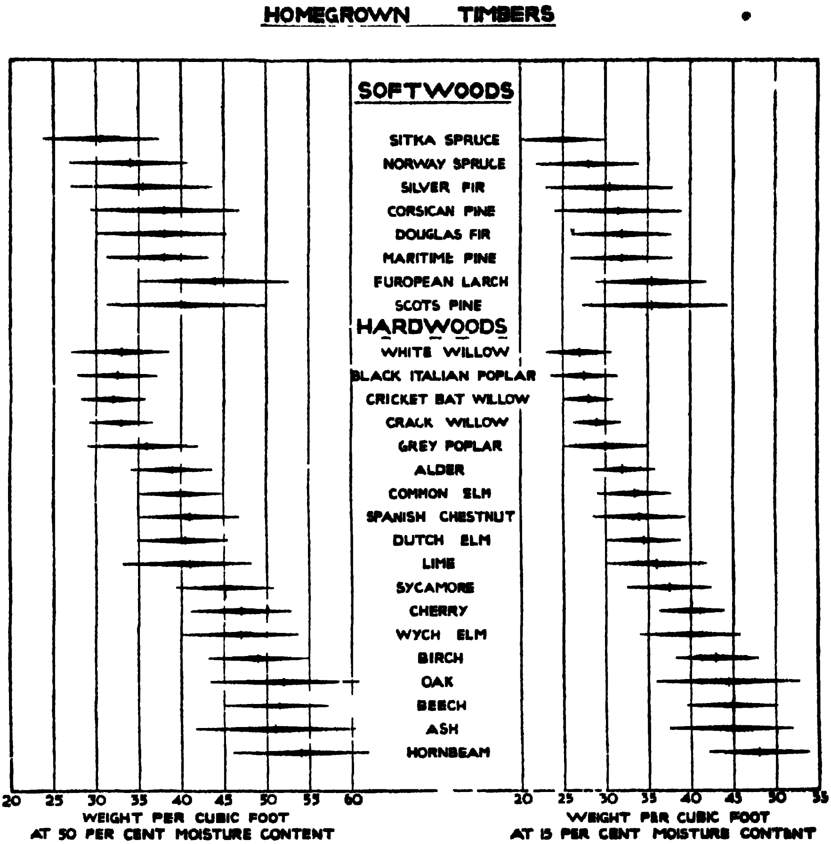


FIG. 24.—Mean weights and range in weights per cubic foot of home-grown timbers

By courtesy of the Director, F P R L, Princes Risborough

investigated. Variation in density within a tree is by no means haphazard.

As a general rule the heaviest wood is found at the base of the tree, and there is a gradual decrease in density in samples from successively higher levels in the trunk. At any given height in the trunk there is usually a decrease in density from the pith to the outside of the tree in ring-porous hardwoods, but in softwoods the position is reversed, and the heaviest wood is usually found near the outside. In diffuse-porous woods, however, in passing

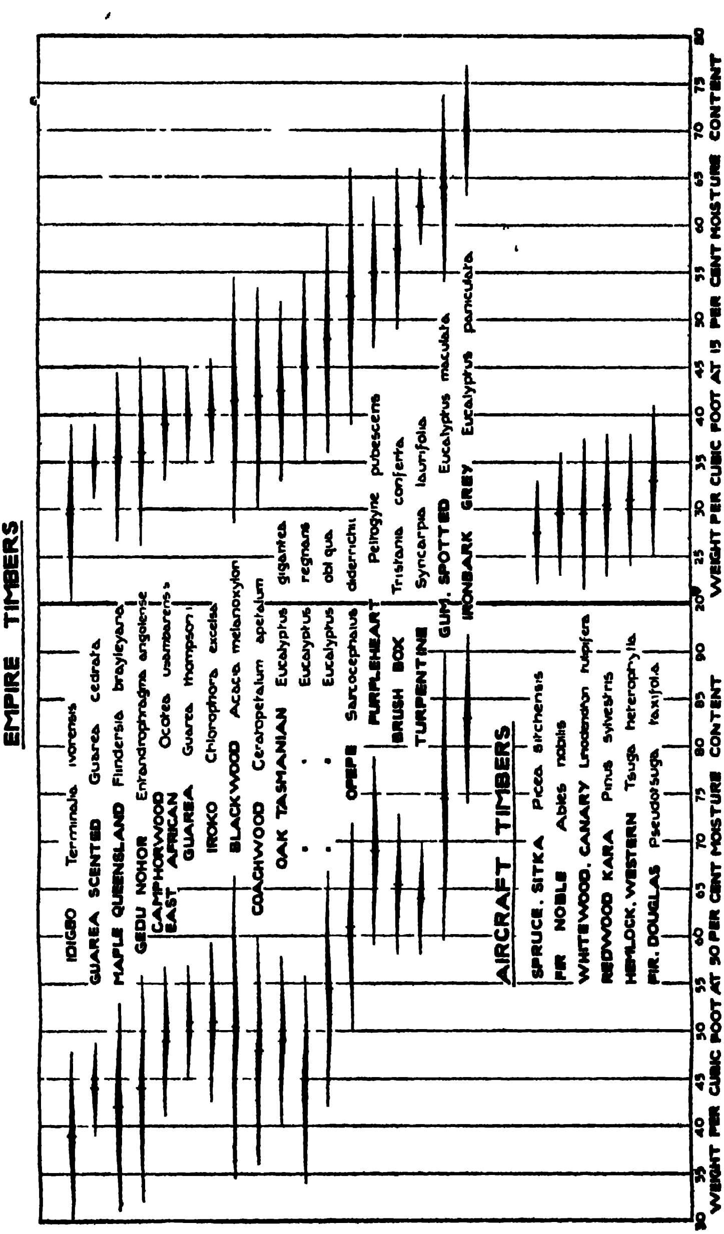


FIG. 25.—Mean weights and range in weights per cubic foot of some Empire and aircraft timbers. (*Note*: the names are not all in accordance with the British Standards Institution's revised list of standard names)

By courtesy of the Director, F.P.R.L., Princes Risborough

from the pith to the outside of the tree there is at first a slight increase and then a gradual decrease in density.

THE PRACTICAL SIGNIFICANCE OF DENSITY

The density of wood is of practical interest because it is the best single criterion of strength. This generalization, however, requires qualification. Density is of limited value in determining the strength properties of individual pieces of wood, because of the influence of other factors discussed in more detail in Chapter VIII. It is useful for indicating the lower limit for a species, below which a specimen will invariably be weak, compared with average material of that species. A relationship exists between specific gravity and strength because these properties depend to a greater or lesser extent on the thickness of the walls of individual cells, and on the proportions of the different kinds of tissue in each piece of wood. If the cell walls are thicker in one sample than they are in another the ratio of wood substance to cell cavity will be greater and, in consequence, the specific gravity will be higher. The proportions of the different kinds of tissue are important because fibres, for example, have thicker walls than parenchyma cells, and if the proportion of fibres is greater in one sample than it is in another, the specific gravity will be higher.

Two other factors modify the importance of specific gravity as a criterion of strength, namely the arrangement of the individual cells, and the physico-chemical composition of the cell walls. If, for example, the parenchyma is distributed in broad layers these may constitute planes of weakness along which the timber will shear, despite a relatively high density for the sample as a whole. It has now been established that the physico-chemical composition of the cell wall is the major influence in determining the strength properties of individual pieces of wood; in particular, the degree of lignification of the cell walls has a direct bearing on most strength properties. For example, tests have indicated that, for timbers of equal density and moisture content, tropical species are less resistant to shock, but are stronger in compression parallel to the grain, than timbers from temperate regions. This can be explained by differences in the chemical composition of the cell walls, in particular, a higher lignin content in the cell walls of tropical species.

CHAPTER VIII

THE STRENGTH PROPERTIES OF WOOD

DEFINITIONS

It requires no special knowledge to appreciate that the strength of a timber has an important bearing on suitability for a particular purpose. A timber for beams, posts, or struts, in buildings should possess different qualities from one required for spokes, hubs, or axles, of carts ; timbers for sports goods and tool handles would not necessarily make good chopping blocks or bearings for machinery, and so on.

The term strength applied to a material such as wood refers to the ability of the material to resist external **forces or loads** tending to change its size and alter its shape The effect of applying external loads to a body is to induce internal forces within the body that resist changes in size and alterations in shape. These forces are called **stresses** ; they are expressed in pounds per square foot or grams per square centimetre The changes in size or shape are known as **deformations or strains.** If the load is small the deformation is small, and when the load is removed there is a complete or partial recovery to the original size and shape, depending on the **elasticity** of the material. Up to a point the deformation or strain is proportional to the load ; this point is called the **limit of proportionality.** Beyond this limit the deformation increases more rapidly than the load. The point beyond which it is impossible to increase the load without establishing a permanent change in shape, or **permanent set,** is called the **elastic limit.** As wood is not a perfectly elastic material it is more usual to determine the load at the limit of proportionality rather than at the elastic limit. If the load applied exceeds the forces of cohesion between the tissues a rupture or **failure** occurs. The load required to cause such failure is called a **maximum load,** *e.g., fibre stress at maximum load* is the greatest resisting stress or stress the fibres are able to exert before failure.

It is important to appreciate that the word strength has little

meaning unless qualified in some way; wood has several types of strength, and a timber strong in one respect may be comparatively weak in another. Different strength properties are called into play, for example, in resisting a **compressive stress** tending to crush a timber, a **tensile stress** tending to elongate it, or a **shearing stress** tending to cause one portion to slide over the remainder. In practice, timber is frequently subjected to a combination of these stresses acting together, although one usually predominates. The ability to bend freely and regain normal shape is known as **flexibility**, and the ability to resist bending is called **stiffness**. The **modulus of elasticity** is a measure of the relation between stress and strain within the limit of proportionality, providing a convenient figure for expressing the stiffness or flexibility of a timber: the greater the modulus of elasticity the stiffer the timber, and, conversely, the lower the modulus of elasticity the more flexible it is. For each type of stress there is a separate modulus of elasticity. The term **brittle** is used to describe the property of suffering little deformation without breaking, whether the load necessary to cause deformation is large or small. It may be observed that brittleness does not necessarily imply weakness. For example, both cast iron and chalk are brittle substances, although the loads required to cause them to fail are very different.

Toughness is a property that is often used vaguely, sometimes referring to the difficulty or otherwise of splitting, *i.e.*, **fissibility**, sometimes to high resistance to sudden loads, *i.e.*, **shock-resisting ability**; and sometimes to the type of fracture occurring on failure, *i.e.*, a stringy fracture as in flexible timbers, as opposed to a clean break characteristic of brittle woods. In timber-testing laboratories three separate criteria in combination have been used to give a measure of toughness in wood. These are: **shock-resisting ability**, measured by the height of drop of a hammer; **work done to maximum load**, which is a measure of the capacity of a substance to store a considerable amount of energy before failure; and **total work in bending**, which provides an estimate of the ability of a substance to sustain a considerable load after the maximum load has been reached. Throughout this chapter toughness is used in the restricted sense, and refers to the ability of a wood to endure suddenly applied loads, exceeding the limit of proportionality. Authorities are

not agreed as to what test data are the best indication of toughness. Koehler[1] favours figures for work to maximum load in the static bending test, but the Timber Mechanics Section, Forest Products Research Laboratory, Princes Risborough, has devised a separate test (see page 126) that gives values fairly closely related to those from the Izod test, and those obtained from the height of drop of a 50 lb. hammer.

Hardness, like toughness, may have more than one meaning. It may be used to describe resistance to cutting, which is influenced by such factors as deposits of silica in the storage tissue and interlocking of the fibres ; or it may be used with reference to resistance to abrasion or resistance to indentation. The last two properties are inter-related, but only resistance to indentation is easy to measure by standard, readily duplicated, methods. The data obtained from indentation tests have a purely comparative significance, but so long as this is understood the data serve a practical purpose in certain circumstances.

ASSESSMENT OF STRENGTH PROPERTIES

Much empirical knowledge exists regarding the strength properties of a few timbers. For example, the outstanding qualities of oak as a structural timber, the toughness of ash, and the hardness of holly are well known, and similar information is available regarding some of the more common timbers in other countries. An accurate comparison of timbers of different countries, however, can only be made by evaluating their strength properties under standard conditions. The evaluations are based on the measurement of stresses and strains. A stress is expressed in terms of load and sectional area, *e.g.*, in pounds per square inch or per square foot, or simply

$$\frac{\text{load}}{\text{sectional area}}$$

and a strain in linear units in relation to the length of the object undergoing strain, or

$$\frac{\text{deformation}}{\text{original length}}.$$

Before the foundation of modern timber research laboratories,

[1] Koehler, A. : *Causes of brashness in wood.* U.S. Dept. Agric. Tech. Bull. No. 342, 1933.

available data for the strength properties of wood were more or less confined to figures for the few timbers with established reputations in their own countries. The methods used for evaluating such data were by no means standardized, and the small amount of timber tested was inadequate to cover the normal variation met with in different pieces of the same wood. Increasing knowledge of alternative structural materials to wood, and the arrival of several new timbers on the market, created a need for comparative and accurate figures for the strength properties of woods. This led to the establishment of timber-testing laboratories at several centres, and the special demands of the 1914–18 war years saw these laboratories stabilized into permanent Government institutions. Laboratories are situated at Princes Risborough, England: Ottawa, Montreal, and Vancouver, Canada; Madison, U.S.A.; Melbourne, Australia; Dehra Dun, India; and Sentul, Malaya.

METHODS OF DETERMINING THE STRENGTH PROPERTIES OF WOOD

Two alternative methods of determining the strength properties of wood are available: service tests and laboratory experiments. Service tests have the advantage that they are carried out under the conditions to which timber is exposed in use, and such conditions, however nearly imitated, cannot be exactly reproduced in the laboratory. On the other hand, the data take much longer to collect, external factors likely to influence strength properties are more difficult to control, and the decentralization of the experiments increases their cost. In the circumstances, laboratory tests provide a practical solution. In the laboratory two classes of tests are made: tests on small, clear specimens, and tests on timber in structural sizes. The former are of value for comparative purposes, and they provide an indication of the different strength properties of individual timbers. Since the tests are designed to avoid the influence of knots and other defects the results do not indicate the actual loads that structural members can carry, and a reduction factor must be applied to obtain safe working stresses. Tests on timber of structural size more nearly reproduce service conditions, and they are of particular value because they allow for defects such

as knots and splits. They have the disadvantage of being costly, because of the large amount of timber required, and the length of time needed to load larger-sized test "pieces" to the point of failure. Moreover, the personal factor is of more importance in the selection of test material in large sizes of uniform quality, compared with small-sized pieces.

The procedure for tests on small, clear specimens has been standardized. As the strength properties of wood are greatly influenced by its moisture content (see page 134), tests are made separately on green material, *i.e.*, freshly-felled timber, and on material dried to a standard moisture content; usually 12 per cent. moisture content, the timber being brought to this moisture content in special conditioning chambers, or the tests are made on air-dry material of known moisture content and the strength figures obtained are corrected to the standard moisture content Precautions are taken to eliminate certain other factors liable to cause variation in strength properties. For example, the size of test pieces has been standardized, and, since it has been shown that the ultimate strength properties of a piece of wood are affected by the rate of strain, all test specimens in each test are loaded at a fixed and constant rate. For a full-scale test it has become usual to select material from five healthy trees of merchantable size, and characteristic of the average in the locality, to allow for variation in different pieces of wood of the same species. If the timber is of sufficient importance, full-scale tests are made on consignments from more than one locality, involving the testing of material from ten, fifteen, or more trees.

Tests on small, clear specimens of many different timbers have now been carried out, and, in spite of the limitations of the data obtained, the tests are of considerable practical importance: the published figures for different timbers are strictly comparable because the method of testing has been standardized, and the figures themselves can be used in calculations of safe working stresses because appropriate correction factors have also been determined. The usual tests, and their practical application, are described below.

DESCRIPTION OF THE TESTS

Compressive strength.—Plate 40, fig. 1 illustrates the apparatus used for testing compressive strength perpendicular

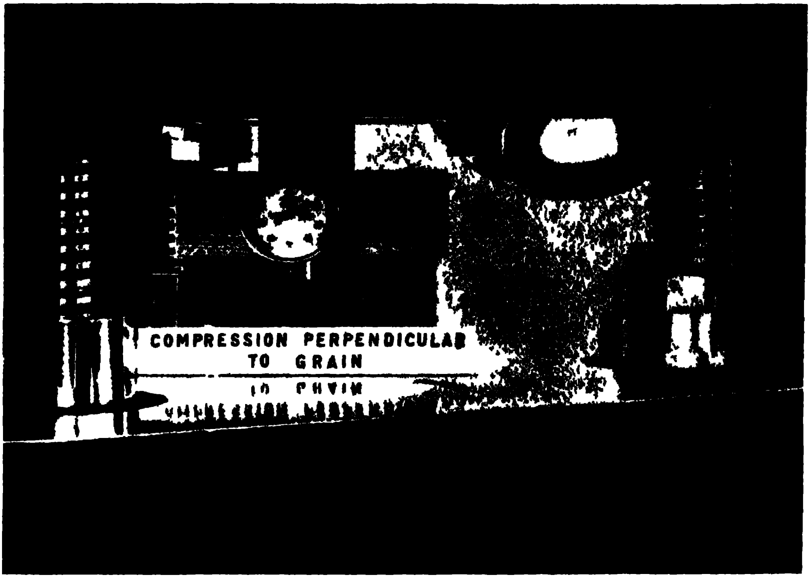


Fig. 1

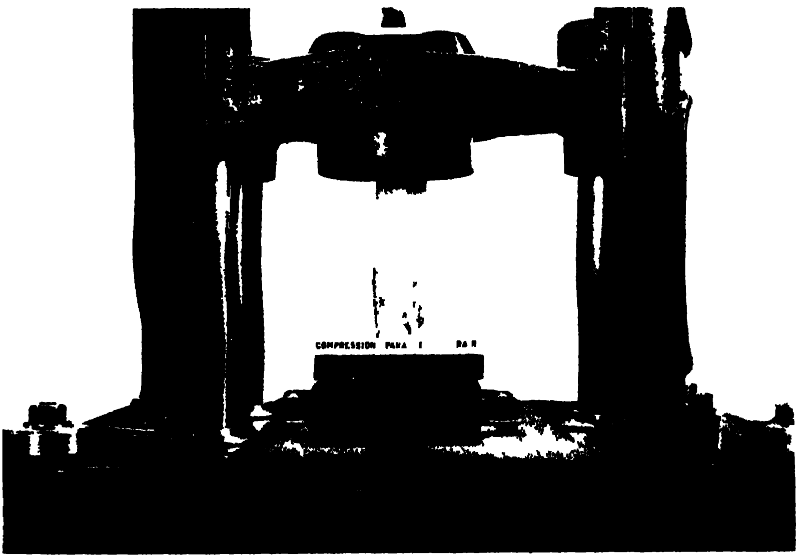
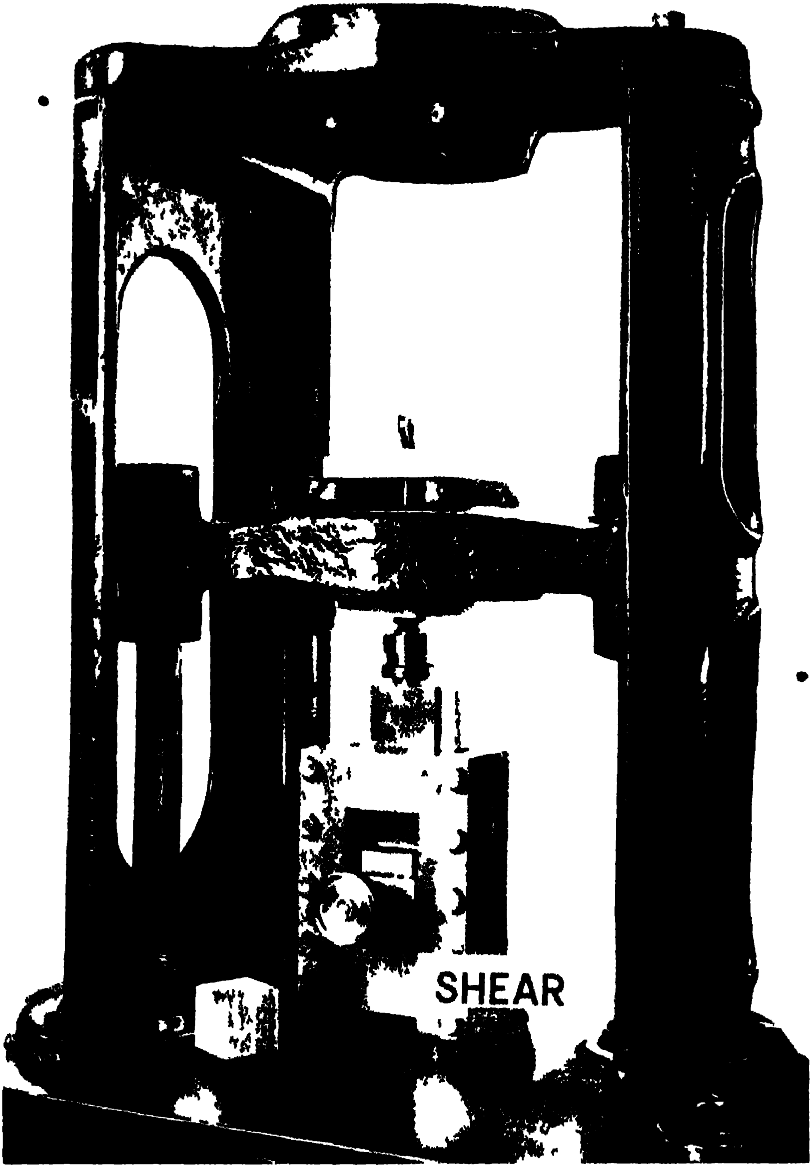


Fig. 2 Illustrating the testing machines, the test pieces, and method of applying the load in compression perpendicular and parallel to the grain

Photo by F. P. R. L., Princes Risborough

PLATE 41



The load is applied over a portion of the cube illustrated on the base of the testing machine. Formerly the specimen was cut away leaving a projecting lip and the load was applied to the stepped portion.

[illegible]

to the grain. The test pieces are 6 in. in length along the grain, and 2 in. square in section, with two radial surfaces. The load is applied to one of the radial surfaces through a plate 2 in. wide, placed centrally with the length of the test piece, compressing the latter over an area of 2 in. square. Readings of deflection and load are taken simultaneously. The stress computed is the fibre stress at the limit of proportionality; it is calculated by dividing the load in pounds, over the bearing surface in square inches. The data from tests of compressive strength perpendicular to the grain are of the same order as those obtained from indentation tests used for assessing hardness (see page 127). High values for resistance to crushing in compression perpendicular to the grain are indicative of woods suitable for use as sleepers, rollers, wedges, bearing blocks, bolted timbers, and other similar purposes.

Plate 40, fig. 2 illustrates the apparatus used for making tests in compression parallel with the grain. The test pieces are 8 in. in length along the grain, and 2 in. square in section. The test piece is placed on end on the flat surface of a hemispherical bearing, and the load is applied through a plate acting on the full sectional area of the test piece, and parallel to the grain of the wood. The test piece is strained in compression at a uniform speed of 0·024 in. per minute until complete failure occurs; deformation, at regular increments of load, is measured in about 20 per cent. of the specimens, and the maximum load at the point of final failure in all specimens. The calculations made, in pounds per square inch, are (a) the maximum crushing strength, (b) fibre stress at the limit of proportionality, and (c) modulus of elasticity; [1] and, in inch-pounds per cubic inch, (d) the elastic resilience, or work to elastic limit.[2]

High strength in compression parallel with the grain is required of timber used as columns, props, posts, and spokes As a rule such members have a relatively great length in comparison with their sectional area, and, in consequence, they are likely to fail in bending before the full crushing force is applied.

[1] $$\frac{\text{Load at limit of proportionality} \times \text{original length}}{\text{Area of cross section in square inches} \times \text{total shortening at the limit of proportionality}}.$$

[2] $$\frac{\text{Load at limit of proportionality} \times \text{total shortening at the limit of proportionality}}{\text{Twice the volume of the test sample in cubic inches}}.$$

To avoid this difficulty in mechanical tests the samples are of relatively large cross-sectional area for their length. Plate 42, fig. 1 illustrates the types of failure that occur in standard-size test specimens subjected to a compressive stress parallel with the grain. Figures from this test are probably the best single criterion of the strength properties of a timber.

Shearing strength.—Plate 41 illustrates the test piece and apparatus used for determining shearing strength parallel with the grain. The test is arranged so that the shearing stress acts radially in half the test pieces and tangentially in the remainder. The load is applied to the top surface of the test piece and shears the specimen in two. The property measured is the load at complete failure, *i.e.*, the total load required to shear the specimen in two. Strength in shear perpendicular to the grain is not measured because timber would fail from other causes before the maximum load could be applied.

Tensile strength.—Plate 42, fig. 2 illustrates the test sample and apparatus formerly used in making tests of tensile strength perpendicular to the grain. The stress measured was that required to pull the specimen in two, and was calculated as follows :—maximum load in pounds to produce failure, divided by the minimum sectional area over which the force is acting, measured in square inches. Strength in tension parallel with the grain was usually not determined, because, although wood is strongest in this property, there are difficulties in the way of making the tests, and, in practice, timber would fail from other causes first.

A practical application of tensile stresses is in tie beams loaded from above : failure occurs through bending, which tends to elongate the fibres on the under side of the beam while compressing those in the upper layers. High tensile strength is also of special value in timber subjected to steam bending. The type of failure that occurs depends on the nature of the wood : thin-walled fibres break in two, thick-walled ones pull apart in the neighbourhood of the primary walls.

The test described above has been abandoned in most laboratories because it was discovered that the stress set up in the test piece was not one of pure tension. More accurate tension tests have since been devised, but the preparation of the test pieces is difficult and takes time, so that they are not always included in a standard series of tests.

PLATE 42

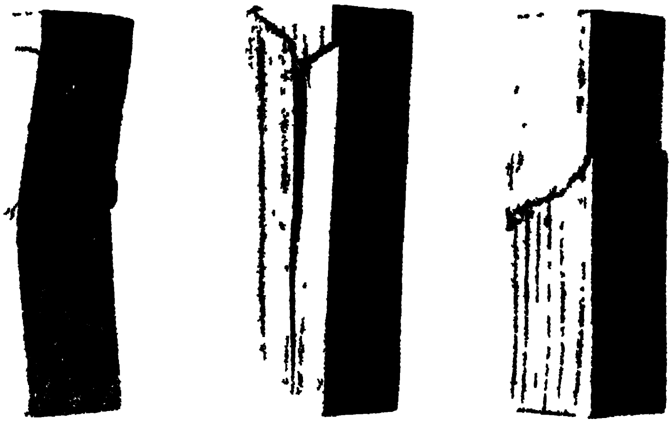


FIG. 1. Types of failure in compression parallel to the grain

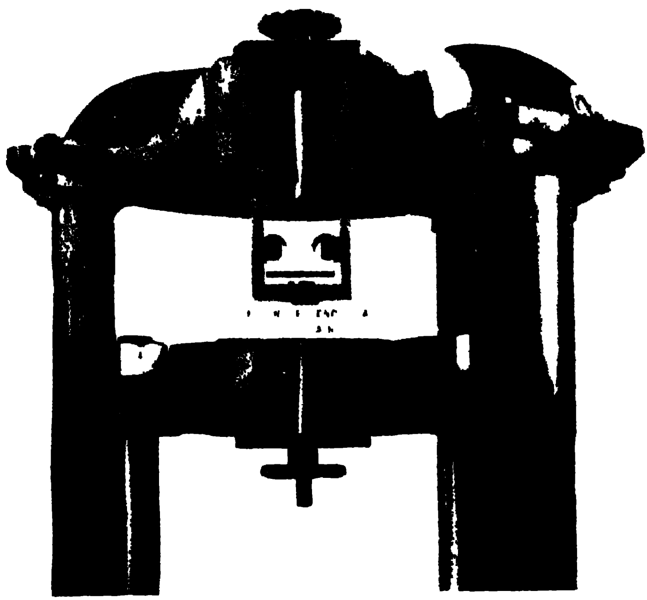


FIG. 2. Illustrating the testing machine, the test piece, and method of applying the load in tension perpendicular to the grain

Photo by F P R L Princes Risborough

PLATE 43

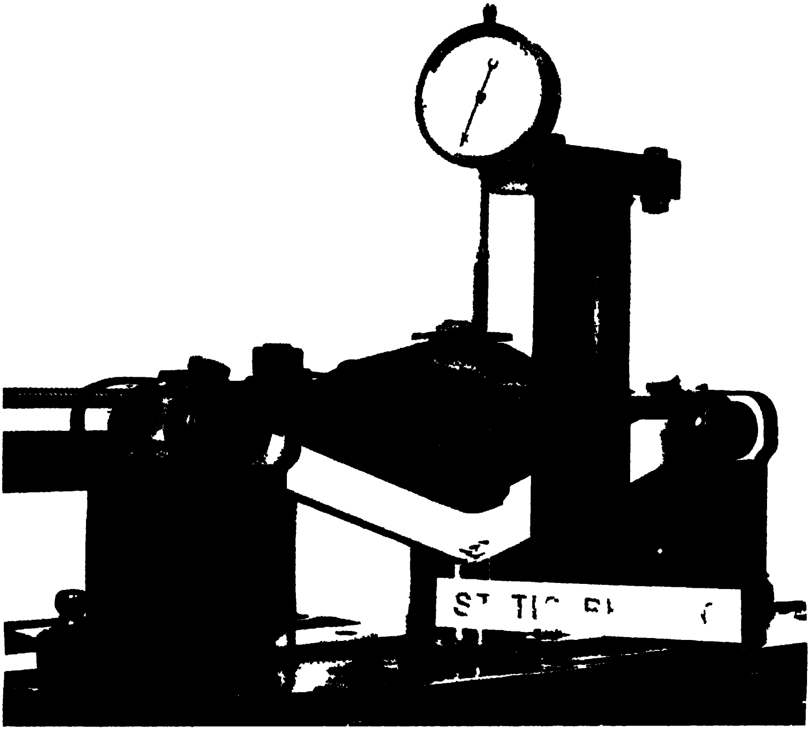


FIG. 1. Illustrating the testing machine, the test piece, and method of applying the load in static bending tests.

FIG. 2. Types of failure in static bending and impact bending tests.

Photos by F. P. R. L., Princes Risborough

Static bending (*cross breaking strength* or *strength as a beam*).—The three strength properties so far discussed have been considered separately, but static bending tests measure the effect of these stresses operating together. Plate 43, fig.* 1 illustrates the apparatus used in such tests. The test pieces are 30 in. in length along the grain, and 2 in. square in section. The test piece is supported at both ends, with the ends free to move, and the heart face is always uppermost; the supports are 28 in. apart. The load is applied at the middle of the span, and at such a rate as to deflect the test piece 0·015 in. per minute; readings of deflections and load are taken simultaneously. The calculations made are: (a) fibre stress at the limit of proportionality, (b) fibre stress at maximum load, (c) modulus of elasticity, and (d) work in bending. The formulae employed in these calculations are as follows:

(a) *Fibre stress at the limit of proportionality:*

$$r = \frac{1{\cdot}5\,P_1 L}{bh^2}$$

where r = fibre stress at limit of proportionality in pounds per square inch,
P_1 = load at limit of proportionality in pounds,
L = span, *i.e.*, distance between the points of support in inches,
b = breadth or width of the test piece in inches,
h = thickness or depth of test piece in inches.

(b) *Fibre stress at maximum load:*

$$R = \frac{1{\cdot}5\,PL}{bh^2}$$

where R = the fibre stress at maximum load (or modulus of rupture) in pounds per square inch,
P = the load in pounds,
and L, b, and h, are as in the previous formula.

(c) *Modulus of elasticity:*

$$E = \frac{P_1 L^3}{4\,Dbh^3}$$

where E = modulus of elasticity,
D = deflection in inches,
and P_1, L, b, and h, are as before.

(d) *Work in bending.—Whereas formulae (a) and (b) above*

give values for the loads sustained at different stages, work in bending is the cumulative energy consumed in reaching these stages, and is expressed in inch-pounds per cubic inch.

The test, as described, introduces shear stresses that are unimportant when comparison of bending qualities of different timbers are made from the data obtained from the test. The influence of shear stresses should, however, be eliminated when accurate figures for bending strength are required for purposes of design. This is done by applying the load at two points, equidistant from the points of support. In tests on small, clear specimens a beam, 40 in. in length and 2 in. square in section, is substituted for the smaller beam; it is supported similarly; but it is loaded at two points as described. The figures obtained from this modified static bending test are for pure bending, without shear.

Static bending is a measure of the strength of a material as a beam. In the resting position the upper half of a beam is in compression and the lower half in tension. Midway between the upper and lower surfaces is the neutral axis where both compressive and tensile stresses are theoretically nil. A shearing stress operates along the neutral axis. The result of applying a load in the middle of the span is to deflect the beam out of the horizontal. This causes a shortening of the fibres on the upper, concave surface, and an elongation of those on the lower, convex surface. As the load increases compression failures develop on the upper surface, and the neutral axis moves towards the lower surface. The subsequent sequence depends on the kind of wood and its physical condition. For example, in unseasoned wood the initial failure is a compression failure immediately below the point of loading, followed by either a tensile failure on the lower surface, or horizontal shear along the neutral axis. Examples of the types of fracture that occur in static bending tests are illustrated in Plate 43, fig. 2. The clean breaks seen in the upper two test pieces (Plate 43, fig. 2), usually described as "short in the grain", are characteristic of brittle timbers; the bottom test piece (Plate 43, fig. 2) shows a typical shear failure.

The load any member can sustain is dependent on the span, *i.e.*, the distance between the points of support, and on the sectional area of the member. The mathematical relationships

between these three dimensions, however, are not directly proportional. For example, the effect of doubling the span is to halve the load that a beam of the same sectional area can carry. The effect of doubling the width of a beam, other factors remaining constant, is to double the load that can be sustained, but to double the depth of a beam is to increase the maximum supportable load fourfold. Because of this, beams are made rectangular, with the greater dimension in depth. There is, however, a practical limit to the magnitude of the ratio of depth to breadth in beams; a ratio greater than 4 to 1 introduces a tendency for the member to twist when loaded.

Loads applied to joists and beams involve bending stresses, but in selecting suitable sections for such members it is often necessary to allow for more than the minimum strength in bending to avoid sagging of floors, and, particularly, the cracking of plaster ceilings beneath. In other words, adequate strength in bending does not necessarily ensure adequate stiffness when the permissible deflection is very small. The reason for this is that timber, like most other materials, is subject to fatigue or, more correctly with timber, to creep. Recent research has shown that the mechanical properties of wood are appreciably affected by the duration of loading, and stiffness is the property most affected: deflection of a green timber loaded to its ordinary working stress may be two to four times as great under long-continued loading, compared with short-time loading. Hence, for many purposes a timber may be sufficiently strong in bending, but not sufficiently stiff, when required to support loads of long duration; unless allowance is made for this, deflection will, in time, become excessive. To offset this possibility, and thereby to eliminate sagging in horizontal beams, it is recommended that in computing for design purposes provision should be made for accommodating a load equivalent to the live load, plus three times the dead load. This ensures that, provided there is no over-loading subsequently, the "permissible deflection" initially selected will not be exceeded throughout the service life of the beam.

The limitations imposed by the effect of long-term loading on deflection can often be countered, without adding to constructional costs and sometimes even lowering them, by using lower grade timber but of greater depth. The lower grade timber will have a lower value for fibre stress at maximum load than the

superior grade, but, by increasing the depth sufficiently, the resulting modulus of rupture is adequate for the loading conditions to be accommodated. Stiffness varies as the cube of the depth, and is less affected by grade of timber, compared with strength in bending. Thus, by allowing greater dimensions to provide for adequate bending strength in a lower grade of timber an even greater increase in stiffness is obtained.

Impact bending.—Plate 44, fig. 1 illustrates the apparatus used in impact bending tests. The test pieces are of the same size as those used for static bending tests (30 in. in length and 2 in. square in section), and they are supported similarly, except that the ends are not entirely free to move. The test consists in dropping a weight of 50 to 100 lb., depending on the strength of the timber, from successively increasing heights on to the centre of the test piece, the test being continued to the point of complete failure or a deflection of 6 in. In some laboratories a record of height of drop, deflection of the test piece, and permanent set, is obtained automatically until a drop of 12 in. is attained, by means of a recording drum and stylus pen incorporated in the test apparatus. The data collected from impact bending tests are :—(1) fibre stress at the limit of proportionality, (2) modulus of elasticity, (3) work in bending, and (4) height of drop to cause failure or a deflection of 6 in.

Other tests are sometimes used to measure shock-resisting ability. The Timber Mechanics Section of the Forest Products Research Laboratory, Princes Risborough, use specimens $\frac{5}{8}$ in. square in section and 10 in. long ; this specimen is freely supported near the ends and broken transversely by a single blow from a falling pendulum. The data from these tests are for total work to complete failure ; that is, the energy absorbed in fracturing the test sample. In the Izod test the specimen is $\frac{7}{8}$ in. square in section, and a notch of standard shape is cut across the grain the full width of the piece, and at right angles to its length. The specimen is firmly clamped just below the notch, and held in a vertical position. A heavy pendulum is then allowed to strike the specimen and break it, and from the reduction in amplitude of the swing of the pendulum it is possible to calculate the energy absorbed in fracturing the specimen.

The shock-resisting properties of wood are considerably in excess of the maxima for sustained loads. Shock resistance is an

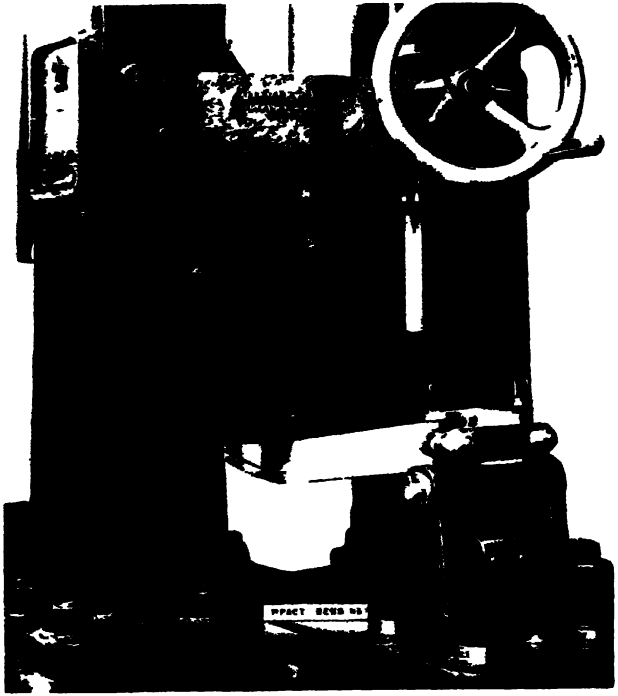


FIG 1 —Illustrating the testing machine, the test piece, and method of applying the load in impact bending tests The 50 lb hammer is in the dropped position

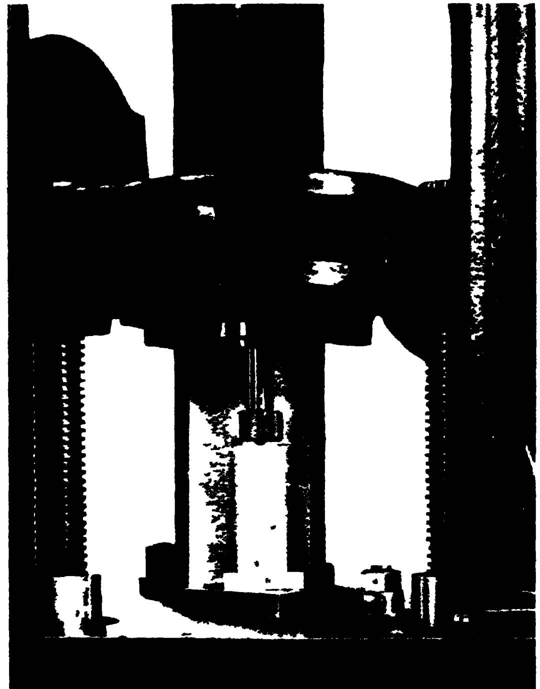
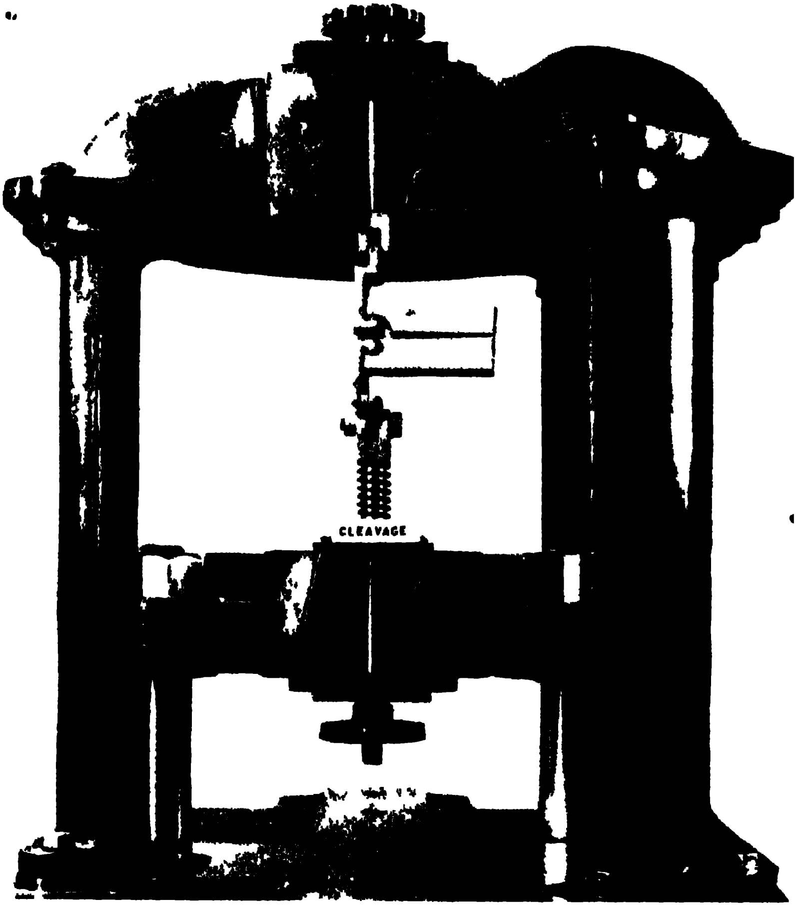


FIG 2 —Illustrating the testing machine, the test piece, and method of applying the load in the hardness test

Photos by F P R I Princes Risborough

PLATE 13



Illustrating the testing machine, the test piece and the method of applying the load in cleavage tests

Photo by [illegible]

essential quality of timber for hammer handles, athletic goods, and similar purposes. Timbers of this class are popularly said to be "tough", and in this case the word is used in the same sense as throughout this chapter.

The combination of resistance to impact bending and the character of failing gradually is sometimes of special value. In places where it is impossible to forecast the exact load a wooden member may have to carry, as in mine timbers, it is a distinct advantage to employ a timber that will fail gradually, so that warning of impending collapse is given. On the other hand, it is a mistake to confuse the character of failing gradually with total strength properties. A timber may have high strength properties without being particularly resistant to sudden loads in excess of its maximum fibre stress in static bending: it is stiff rather than flexible. Such a timber will support a much greater total load than one with, for example, lower strength properties but better resistance to sudden loads in excess of its maximum fibre stress. Only in circumstances where it is impossible to predetermine probable loading, and the warning of impending collapse is invaluable, would the selection of the latter timber, at the expense of the former, be justified.

Hardness.—Plate 44, fig. 2 illustrates the apparatus used for making hardness tests. The test consists in measuring the force required to imbed the hemispherical end of a steel rod 0·444 in. in diameter into a test piece to a depth of 0·222 in. Penetrations are made on the radial, tangential, and end surfaces. This test measures only resistance to indentation, but the popular conception of "hardness" embraces ease of cutting. This latter property is dependent on the nature of the grain, and the presence of silica and other substances in the cell cavities, quite as much as on the resistance to indentation. Several instances exist, particularly among tropical timbers, of woods that are at the most only moderately hard, measured by resistance to indentation, but which are extremely hard on cutting tools, *e.g.*, white meranti and Queensland walnut.

Hardness is of value in timber for paving blocks, flooring, bearings, and other similar purposes, although for paving blocks and flooring uniform wearing qualities are of greater importance than absolute hardness. Wearing qualities are influenced by the method of conversion: flat-sawn material will not wear so

uniformly as quarter-sawn. Moreover, even good wearing qualities do not complete the requirements in timber for paving blocks and flooring. For the former, low absorbent qualities are sometimes at least as important, and for both purposes low shrinkage, with corresponding small "movement"[1] in service, is most desirable. Further, for flooring in particular, very hard timbers, which are naturally very dense and tend to be of very fine texture, may be too slippery when planed to provide a safe surface, and they are always more noisy to walk upon than the less dense timbers that may have poorer wearing qualities.

Cleavability.—Plate 45 illustrates the test piece and apparatus used in cleavability tests. Half the pieces are cut radially and half tangentially, and the cleavability in the two directions is calculated separately. The stress measured is the load in pounds necessary to split the specimen in two, divided by the width in inches of the section at the point of application of the load. The results obtained may be considerably influenced by irregularities in the grain of particular samples. Interlocked grain, for example, provides a resistance to splitting traceable to the arrangement in the longitudinal plane of the elements in that sample. In consequence, data from cleavability tests should be regarded solely from the comparative standpoint and not from that of absolute values. The factor that determines resistance to splitting is the arrangement of the different tissues in relation to one another: for instance, broad rays provide planes of weakness in the radial direction, and tangential series of resin canals (as in timbers of the *Dipterocarpaceae*) planes of weakness in the tangential direction. As a general rule straight-grained timbers split more readily radially than tangentially, and more readily dry than "green", but timbers with markedly interlocked grain split more readily tangentially and are often extremely difficult to split radially.

The readiness or otherwise of a timber to split, which cleavability denotes, has a practical application in certain circumstances. In firewood, and material for the manufacture of tight barrels, charcoal, and hand-split shingles, high cleavability is a very desirable asset; for nail- or screw-holding purposes, as in packing-case manufacture, high resistance to cleavage is an essential quality.

[1] For a definition of "movement" see page 91.

INFLUENCE OF MICRO-STRUCTURE OF CELL WALLS

It has already been indicated that, in general, the strength properties of wood are roughly proportional to specific gravity, that in softwoods and ring-porous hardwoods strength is dependent on the proportion of late wood in the growth ring, and that very slowly-grown specimens of timber are below the average for the species in both specific gravity and strength. These conclusions sum the experience of generations of timber users, and have been confirmed by the examination and mechanical testing of many thousands of specimens, but it cannot be too strongly emphasized that they are generalizations, and questions still remain as to how far specific gravity may be regarded as a guide to the properties of the individual piece of timber, and what other properties play a part in determining strength. It has been established, for example, that strength properties vary with position of a sample in the tree, and that some localities produce timber of more than average strength for the specific gravity.

Differences in the chemical composition of the cell wall were suspected of having a major influence on the strength properties of individual pieces of wood. Preliminary investigations disclosed that such abnormal tissue as compression and tension wood has different strength properties from normal wood of the same species and density. On the other hand, the presence of extractives appeared to have little influence on the strength properties of wood, and it was established that sound sapwood is not inferior in strength properties to sound heartwood of the same species.

S. H. Clarke of the Forest Products Research Laboratory, Princes Risborough, therefore investigated the influence of the micro-structure of the cell wall in some detail. Clarke directed his attention in the first place to two strength properties, namely, resistance to longitudinal compression and toughness. In the course of a typical investigation some 1000 specimens of beech, from comparable parts of the tree, and representing 36 trees from 6 localities, were tested to destruction under longitudinal compression: the specific gravity of each specimen was determined and a microscopic examination was made of each. When specific gravity was plotted against strength the points for the various specimens were found to be scattered over an elliptical area. To

avoid confusion only a few individual points are shown in Fig. 26; the line AB is the computed line of best fit to all the points. Individual specimens of the same specific gravity were found to differ

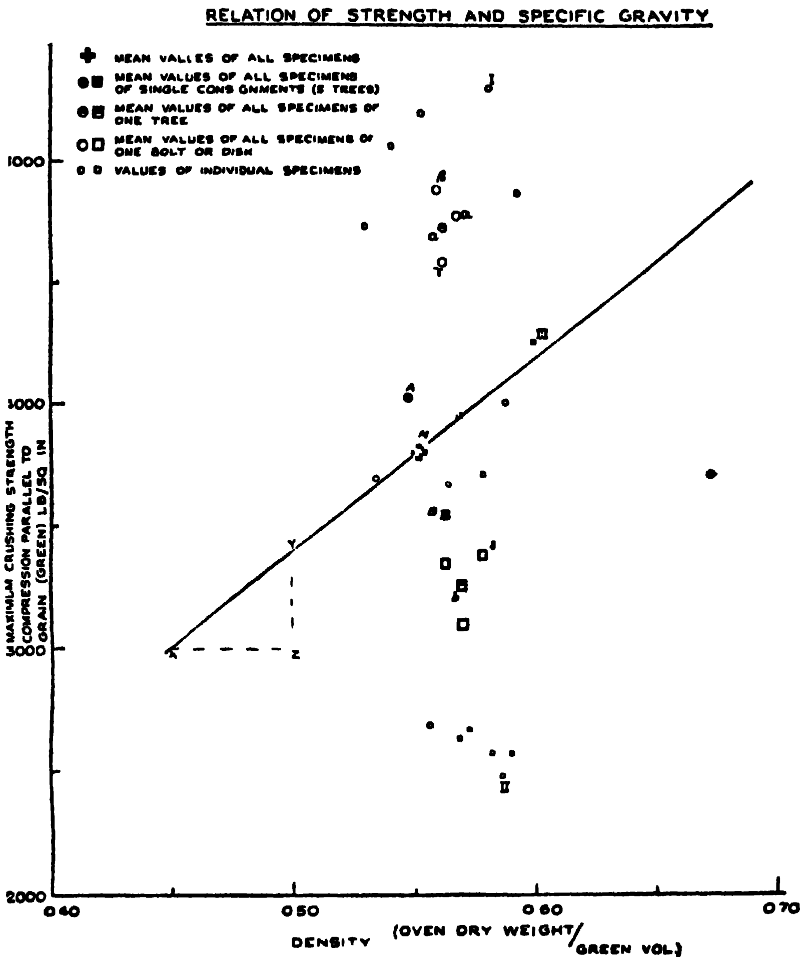


Fig. 26 —Relation of strength and specific gravity

By courtesy of the Director, F P R L, Princes Risborough

by as much as 2700 lb. per sq. in., indicating that maximum crushing strength was influenced to an even greater degree by some other factor than density. A point of interest brought out by Fig. 26 is that the points of specimens from the same tree fell fairly close together; actually they were in small ellipses within the large

ellipse. A similar relationship was found to hold in ash, oak, willow, and sweet chestnut.

In the ring-porous woods it was shown that the composition of the growth ring explained some of the variation in strength, additional to that attributed to variations in specific gravity (which is itself related to the growth rate), but the major variations were still unexplained.

A comparison of specimens matched in respect of specific gravity and growth characteristics revealed that the wide variations in strength were largely dependent on the composition of the cell wall, and it was shown by means of micro-chemical reagents that a high compressive strength was accompanied by a relatively heavy degree of lignification, particularly in the region of the secondary wall of the fibres, while weaker specimens were below the average in this respect. The term lignification is used here in the botanical sense, and refers to a condition of the cell wall revealed by staining reactions and micro-chemical tests. Research has not yet gone far enough to correlate completely the degree of lignification as revealed by micro-chemical tests with the results of chemical analysis, but it is certain that conditions may be recognized that follow the variations in strength.

Variations in toughness were more difficult to explain: while specimens of low density were invariably weaker, it did not follow that those of high specific gravity were tough, and the influence of lignification was not readily apparent. A study of many fractures in specimens that had been submitted to the Izod test indicated that the initial failure usually occurred in the region of the middle lamella, and that failure was usually initiated in a zone of special weakness, for example in the parenchyma, and that the strength of the secondary walls of the fibres rarely came into play.

There were indications, however, of a negative relation between compressive strength and toughness, in that there was a tendency for material that was especially strong under compression to be weak in toughness. An interesting comparison may be observed in Figs. 27 A and B, which show the relations between compressive strength and specific gravity, and toughness and specific gravity, for some 300 timbers. Each point shows the average value for one species of timber. It is at once apparent that, on the average, tropical timbers are stronger in compression

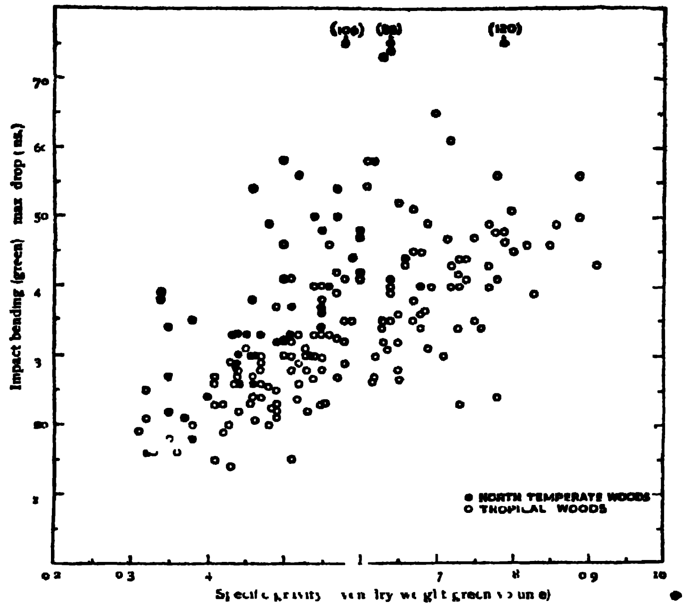


FIG A

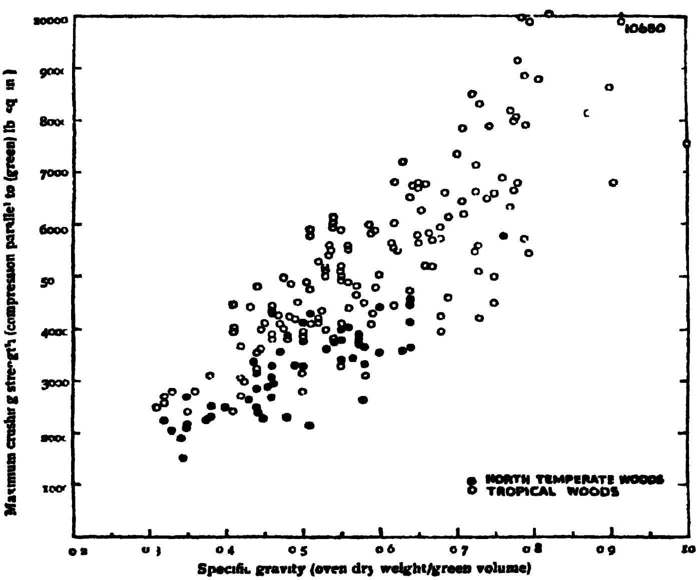


FIG B

FIG. 27.—Comparison of strength properties of temperate and tropical timbers

By courtesy of the Director, F.P.R.L., Princes Risborough

than temperate timbers of the same specific gravity, but that the reverse is true for toughness. Micro-chemical tests revealed the expected difference in the condition of lignification between tropical and temperate timbers. This was not only true as a general condition, but the difference was also revealed between individual specimens of the same species grown under temperate or tropical conditions.

A further comparison of these strength properties has been made in respect of tension wood and compression wood. The former is, on the average, tougher than normal wood but weaker in compression, whereas compression wood is stronger in compression than normal wood of the same specific gravity but less tough. It is well known that tension wood is less strongly lignified, and compression wood more strongly lignified, than normal wood.

Another point of interest is that as wood of most species dries from a green condition it undergoes a reduction in toughness but an increase in compressive strength.

Taken together, these facts point to the importance of the physico-chemical condition of the cell wall as a factor in determining strength properties. It will readily be understood that the composition is determined by growth conditions. Much remains to be discovered of the effect of temperature, water relations, traces of certain elements, etc., in the growing tree on the degree of lignification

In conclusion, it may be reiterated that for most species there appear to be optimum conditions under which trees make the best growth, and that timber produced under these optimum conditions is superior in strength properties to that produced under less favourable conditions. Further, the chemical composition of the cell wall, probably the lignin-content in particular, is influenced by locality; and the fibrillar arrangement of the cell wall is also influenced by growth conditions, in particular the slope of the stem when growing.

INFLUENCE OF MOISTURE IN WOOD ON STRENGTH PROPERTIES

An important factor affecting the strength properties of wood is the moisture content[1] of individual samples. In general,

[1] The term "moisture content" is defined on page 81.

below the fibre saturation point,[1] the mechanical properties of timber increase with decreasing moisture content, although the rate of increase is not identical for the different strength properties. Toughness is an exception to the general rule, since both in work to maximum load in static bending, and height of drop of hammer necessary to produce complete failure in impact bending, there is usually an actual decrease as moisture

TABLE IV

AVERAGE INCREASE (OR DECREASE) IN VALUE OF VARIOUS STRENGTH PROPERTIES EFFECTED BY DECREASING (OR INCREASING) MOISTURE CONTENT 1 PER CENT. WHEN AT ABOUT 12 PER CENT.[2]

Property	Per cent
Static bending :	
Fibre stress at elastic limit	6
Modulus of rupture	4
Modulus of elasticity	2
Work to elastic limit	8
Work to maximum load	* −1
Impact bending :	
Fibre stress at elastic limit	4
Work to elastic limit . .	5
Height of drop of hammer causing complete failure .	−3
Compression parallel to grain :	
Fibre stress at elastic limit	5
Crushing strength	4
Compression perpendicular with grain	
Fibre stress at elastic limit	6
Hardness — end	3
Hardness — side	1
Shearing strength parallel with grain	4
Tension perpendicular to grain	1

content decreases ; certain softwoods, however, *e.g.*, sitka spruce, show an increase in toughness with decrease in moisture content. In other words, dry wood will support a far greater load than green timber, but it will not bend so far before failure occurs ; it is more brittle. It has been found that small, clear specimens of thoroughly air-dry wood (12 per cent. moisture content) have

practically twice the strength in bending and endwise compression of the same material when unseasoned. When kiln-dried to approximately 5 per cent. moisture content the increase in strength may be threefold. Table IV shows the average change in value of various strength properties, effected by an alteration of moisture content by 1 per cent., for timber previously dried to about 12 per cent.

For most purposes the margin of safety in general use is such that the increase in brittleness on drying is not of consequence. Mine timbers, however, are an exception, since it is not always possible to determine what load such timbers will have to carry, and brittleness may become a serious fault.

It must not be overlooked that the development of seasoning defects may offset any increase in strength properties as timber dries. Moreover, the figures given in Table IV are *average* figures for many species, and in using the figures the warning already given about averages should be borne in mind. They are valuable as a general trend, but cannot be applied directly in determining the precise strength of individual specimens. A further point of interest is that timber once dried below a given moisture content, allowed to absorb moisture again, and then re-dried, has slightly lower strength properties, and is more brittle, than material that has never been dried below the given moisture content.

INFLUENCE OF DEFECTS ON STRENGTH

Differences in the mechanical properties of different timbers are obviously dependent on many factors: in particular, the relative abundance of the different kinds of tissue and the arrangement of the individual elements in relation to one another. The micro-structure of the cell wall, and moisture content, have also been shown to be of paramount importance. Various other factors, however, influence the properties of individual samples, *e.g.*, irregularities of grain; splits and checks that develop during seasoning; the presence of rot; and abnormalities in anatomical structure. These different factors are usually classified as defects (*vide* Chapter XI). Many defects reduce the strength properties of wood, but their weakening effect varies with their position in relation to the piece of timber as a whole, and the use to which the timber is put in service, *i.e.*, whether it is used in such a way

that it is exposed to bending, compressive, or shearing stresses, or sudden heavy loads (impact bending) rather than normal, continuous loads. In other words, defects affect different strength properties differently.

The influence of the direction of the grain on the strength properties of wood has already been discussed, *vide* page 62. Sloping grain is the most important in this connection, but in ordinary practice the margin of safety is such that an appreciable degree of tolerance in regard to sloping grain is permissible for most purposes, other than in timbers for athletic goods. In some cases, however, the margin of safety is comparatively small, *e.g.*, in the legs of chairs, when freedom from sloping grain is most desirable.

"Spongy heart"[1] reduces the shock-resisting ability of a timber appreciably, but if it is not extensive it may be of little significance in timbers used as short columns, and it is only slightly more serious in timbers subjected to ordinary static bending stresses. If, however, visible compression failures[1] are also present strength properties are appreciably reduced: any timber likely to be subjected to even half its allowable working stress should contain no compression failures.

All forms of warping[1] reduce the strength properties of wood because loads applied in service will no longer act directly parallel with or perpendicular to the grain. The most serious of these defects is likely to be bend in a long column loaded in compression parallel with the grain: a bend or curvature of 1 in 1000 might reduce the strength by 20 per cent.; further reductions in strength with increases in curvature are not proportional, but appreciably less than a direct ratio.

Splits and checks, that is, actual ruptures of the tissues, naturally affect the strength properties of wood, particularly by reducing resistance to shear. The effect on strength properties is largely dependent on the plane of the splits or checks: they seriously lower the strength of a beam or plank if they occur in a horizontal plane, but they are of little importance in the vertical plane. Hence, checks or splits do not greatly affect the strength properties of a short, straight-grained column.

Knots[1] influence the strength properties of a piece of wood to a varying degree, depending on their size, position, and type.

[1] These terms are defined in Chapter XI.

Strength properties are adversely affected not because the wood of which the knot is composed is ordinarily inferior to normal wood, but because of the irregular grain that occurs in the vicinity of knots. Knots do not lower the stiffness of a timber appreciably, but they reduce its tensile strength. Hence, they are of greater significance in joists, beams, and similar timbers, than they are in columns. In beams, the weakening influence of knots is greatest when they occur in the vicinity of the maximum bending stress and on the bottom of the beam; they are of less importance when they occur near the top of the beam, and of still less significance if they occur near the centre of the depth of the beam. Any one knot will be progressively more serious as its position is farther away from the points of support of a beam. Reduction in strength properties, resulting from knots, increases at a faster rate than the proportional increase in area of the knot.

APPLICATION OF TESTS ON SMALL CLEAR SPECIMENS

The limitations of tests on small, clear samples have already been indicated, but the tests have a very real practical application. For example, in the absence of tests on timber in structural sizes, they are the only sound basis for comparing the relative strength properties of different timbers, and, because external factors are more easily controlled, they are in some respects superior to tests on timbers in structural size. In the absence of the latter tests, and provided correction factors, *i.e.*, factors of safety, are applied to the figures obtained from tests on small, clear specimens, the data may be used in constructional design. There is no doubt that the tendency in the past has been to use timber of unnecessarily large cross section in building work, whereas, if the information now available were applied intelligently, appreciable economies could be effected. American workers have devised reduction factors that attempt to take into account variation occurring within a species and the presence of what may be accepted as a normal amount of degrade resulting from irregularities of grain, splits and checks that develop during seasoning, and similar causes. These reduction factors, which should be used with the figures from tests on small, clear specimens in the green condition, are as follows:

(a) *In bending:*

1/6 in dry places under cover,

1/7 outside, but not in contact with the soil, and

1/8 in wet places,

of the figures for the fibre stress at the maximum load for green timber.

(b) *In compression parallel to the grain:*

1/4 in dry places under cover,

1/4·5 outside not in contact with the soil, and

1/5·5 in wet places,

of the figure for the maximum crushing strength for green timber.

(c) *In shear:*

1/10 of the average of the figures for the radial and tangential shear stresses.

(d) *In side compression:*

1/2·25 of the figure for the compressive strength perpendicular to the grain at the limit of proportionality.

The use of strength data in this way is an advance on former practice, which was too conservative as far as the strength properties of wood are concerned. On the other hand, data from tests on small, clear specimens must be used with understanding. For example, some commercial timbers are the product of several botanical species, and the strength properties of each, as determined by tests, may well show a range between the weakest and the strongest of more than 20 per cent. It would be wasteful always to use the figures for the weakest timber tested, and unwise to employ those for the strongest species. In most calculations it is probable that the mean figures of all the species tested could be used, but it is in such cases that a proper appreciation of the significance of the data is essential. It does not seem advisable to attempt to assess liability to fungal attack in service in a reduction factor, but this is what is done when the reduction factor is reduced from $\frac{1}{6}$th to $\frac{1}{7}$th or $\frac{1}{8}$th, depending on the "site" conditions where the timber is to be used. The practice should be confined to temporary structures, and even with these it must be remembered that there is a tendency to retain them for appreciably longer periods than those originally planned. A

margin is, however, secured by using figures for green material when these are applied to timber that will be at least partially seasoned before being used. The intention is, of course, to provide for strength in excess of the initial calculated requirements, on the grounds that such excess is discounted as decay starts; it is assumed that decay will be detectable before the strength properties of individual pieces of wood have been reduced below the values used in the calculations. The Forest Products Division of the Department of Scientific and Industrial Research in Australia has taken a sound first step in the absence of detailed data. Australian timbers have been classified in four groups, and single values for certain strength properties have been selected for all the timbers in each group. These values, with or without reduction factors in different circumstances, may be used in the standard formulae applied in constructional design. It is obvious that the values selected must err on the side of caution, since the timbers in any one group will vary appreciably in strength properties.

STRESS GRADING

Various factors have been shown to influence the strength properties of wood, and the causes of variation in strength between different pieces of the same timber, in so far as they are understood today, have been discussed. The practical application of this knowledge rests on the availability of rapid means for separating timber into a few broad strength grades. Such means exist; they have been established by experimental procedure and the application of simple mathematical theory.

Research has established that, within certain limits, the strength of wood bears a relation to certain visible defects. Statistical analysis of test data discloses that these conform to simple mathematical laws; in particular, variation follows the normal or Gaussian frequency distribution.

Many measurable properties are influenced by several, often unrelated, causes, which it is frequently desirable to study singly. For example, if a random selection of 1000 men were made, and their heights recorded, it would be possible to construct a graph from these data: the resultant graph is a frequency curve. The heights in the example suggested might be expected to range from 5 to 6 ft 6 in. By arranging the measurements in

one-inch classes we would find that the majority fell near the arithmetical mean of these extremes, and that progressively fewer fell in the classes further removed from the mean. In

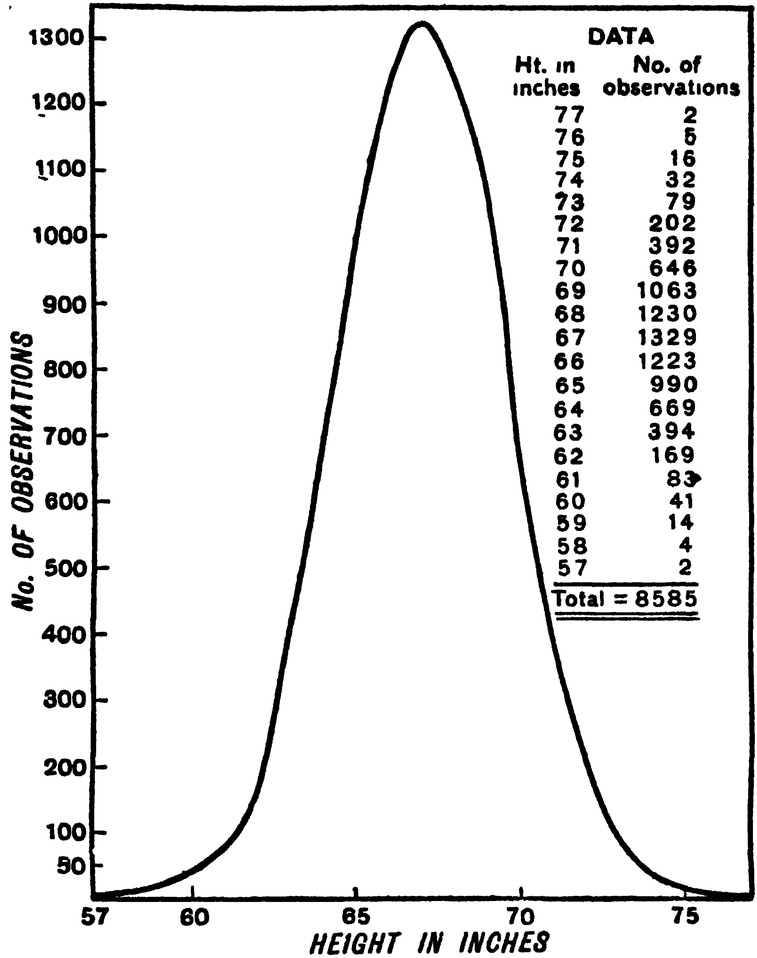


FIG. 28 —Normal or Gaussian frequency distribution. Height in inches of adult males in Great Britain, based on 8585 measurements.

Figures from final report of Anthropometric Committee, 1883

effect, height in adults follows a normal frequency distribution, which can be expressed graphically as in Fig. 28. If we restricted our selection of men to one race, or to those between, say, 9 and 12 stone, we would get different curves from those for men of all races, or men of all weights; the type of

curve would be the same in each case, with the peaks for these different sets of data moved to the right or left. Taking one test at a time, similar frequency curves can be constructed from the test data for wood; an example is given in Fig. 29. Such

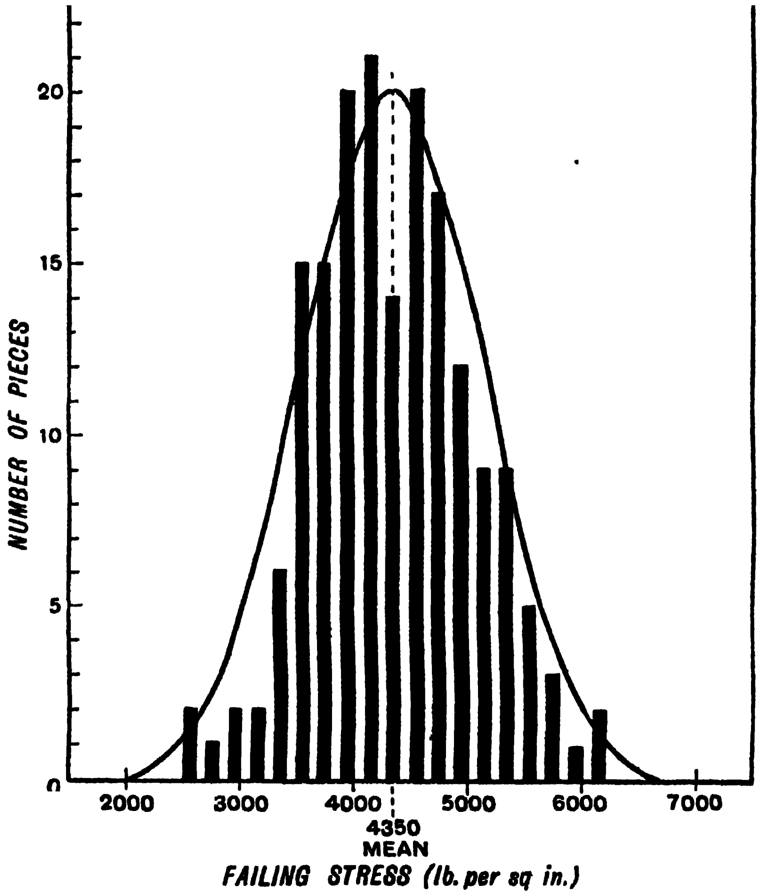


FIG. 29.—Normal frequency distribution of test results. Curve calculated by Mr. P. O. Reece, A.M.Inst.C.E., A.M.Inst.M.&Cy.E., from actual test data

Courtesy of P. O. Reece, Esq.

a figure has been constructed from data for one species in one test. This shows a maximum stress ranging from about 2400 lb. per sq. in. to 6700 lb., with the greater number of pieces around 4350 lb. per sq. in. In any random parcel of 100 pieces of such timber, we might expect one piece to fail at about 2400 lb., another

between 2400 and 2600 lb., perhaps two around 2800 lb., two more at 3000 lb., and so on. The chances of picking the weakest pieces every time are obviously small, and therefore it would be very wasteful to fix the strength for the grade at the minimum of 2400 lb. By accepting the possibility of a small number of pieces failing below a selected minimum, it would be possible to raise this minimum considerably and yet ensure that the bulk of the material was at or above the minimum selected. In constructional work generally, wood is used in built-up structures, the strength of which is considerably above that of the weakest member. Moreover, a factor of safety, or what the Americans not inaptly call a factor of ignorance, is provided in the calculation of stresses. Hence, the inclusion of a few pieces below a certain minimum is immaterial. Having decided on the number of pieces below the minimum that can be admitted, the allowable working stress is determined. The number of admissible potential failures will be governed by the degree of testing employed in the finished article: in aircraft construction, when a high degree of testing is carried out, very much higher working stresses can be admitted than in building construction where little or no testing is done.

As with men, and their heights, the peaks for test data can be influenced by restricting the data studied, and, provided the same percentage of potential failures to be admitted is not varied, the allowable working stress will be raised or lowered with different sets of data. For example, we know that wood of low density has strength values below the mean for the species. It follows that if we exclude all pieces below a certain density, the peak of the frequency curve for, say, maximum strength in bending, for material above this minimum, will be higher than the peak of the curve that includes the whole range of material tested. Further, with the same reservations as to potential failures, the allowable working stress for the former could safely be fixed at a figure greater than for the latter.

Density is not a particularly convenient factor to work with in the timber yard, but such visible features as knots are. The influence of knots can be studied by testing material of the same lengths and sectional area, but with different percentages, measured by area, of knots, and the relevant frequency curves constructed. Separate curves would be provided for knot areas

of 10, 20, and 30 per cent., or any other selected percentages. Admitting the same percentage of potential failures with each, three separate minimum allowable working stresses would be obtained. This is the theory behind stress-grading rules.

The influence of readily assessable features on strength properties are studied, and by determining the maximum knot area, or minimum number of rings per inch, or a combination of such features, the allowable working stresses for different classes of material are determined. By visual inspection it is then possible to arrive at the grade of any piece of timber with assurance that 80, 90, 95, or any other previously selected percentage of such material will possess the minimum strength properties of its grade. Sufficient timber in structural sizes, and containing defects, has had to be tested for the influence of readily observable defects to be accurately determined. From these studies it has been possible to draw up simple rules that make it possible by rapid visual inspection to allocate any piece of timber of the species covered to its correct stress grade. It would have been wasteful to fix the strength of any grade at the minimum value for that grade, since this would mean that in any random parcel of x pieces, $x-1$ could be expected to have a higher maximum stress value than the figure adopted for that grade. It was decided, therefore, to accept a probability, or mathematical chance, of 1 in 40 that no piece would fail below the failing stress fixed for that grade. A factor of safety was then applied, the factor selected being 27/64ths, to give the allowable working stress for the grade. The values that have been accepted for Northern European softwoods are a safe working stress in flexure respectively of 1200 *f.*, 1000 *f.*, and 800 *f.* : *f.* is the stress per sq. in. in bending. This means that the minimum strength as determined by test for the 1200 *f.* grade is $\frac{1200 \times 64}{27}$ or 2844 lb. One piece in 40, or 25 in 1000, would fail at some figure below 2844 lb., but no piece would fail, or rather the chance is one in several thousand that no piece would fail, below the calculated allowable working stress of 1200 lb. per sq. in. The corresponding figures for the 1000 *f.* grade is 2370 lb., and for the 800 *f.* grade 1896 lb. These stress-grading rules are further discussed in Chapter XV.

With such rules it is possible to use wood much more

economically, with certain definite minimum guarantees. The much closer precision in the use of wood that is thereby gained places it in the field of engineering materials. At present only a very few stress grades have been worked out, but the potentialities of this approach to wood are obviously enormous, and the seemingly pointless testing of hundreds of thousands of pieces of wood to destruction takes on an altogether different significance.

CHAPTER IX

THE CONDUCTIVITY, HEAT, AND ENERGY VALUES OF WOOD

HEAT CONDUCTIVITY

In many situations the ability of a substance to resist the passage of heat, electricity, or sound, is of the greatest importance. Dry wood is one of the poorest conductors of heat, and this characteristic renders it eminently suitable for many of the uses to which it is put every day, *e.g.*, as a building material, in the construction of refrigerators or fireless cookers, and as handles of cooking utensils. The handle of an all-metal teapot becomes as hot as the teapot itself in a relatively short space of time, but a wooden one remains comparatively cool. Good quality cooking pots, teapots, and other containers for hot liquids often have small buffers of wood inserted between the vessel and its handle to prevent the passage of heat by conduction to the handle.

The transmission or conduction of heat depends on two factors: (a) the specific conductivity and (b) the specific heat of the intervening material. Although the specific conductivity of dry wood substance is low, that of timber is even lower, for, as we have seen, wood is a cellular substance, and in the dry state the cell cavities are filled with air, which is one of the poorest conductors known. The cellular structure of wood also partly explains why heat is conducted about two to three times as rapidly along, compared with across, the grain, and that heavy woods conduct heat more rapidly than light, porous ones.

The specific heat of a substance is the amount of heat required to raise the temperature of one gram of that substance 1° C. The specific heat of wood is about 50 per cent. higher than the specific heat of air, and four times as high as that of copper. It has already been inferred that the conduction of heat through wood

is a matter of importance in the kiln drying of timber, since one of the aims of this process is to raise the temperature of the interior of planks and boards in the kiln. In these, and similar circumstances, the high specific heat of wood is a disadvantage. Fortunately, the movement of heat is more rapid in green timber and, as wood is usually more or less green when subjected to such treatments, the disadvantage of poor conductivity is less marked. Dry wood conducts heat much more slowly than green timber of the same species because of the water present, which is a much better conductor than air.

One effect of applying heat to a substance is to cause it to expand. Allowances to permit of expansion and contraction, with changes in atmospheric temperature, are made in all-metal structures such as bridges, rails, and steel-work structures generally. Woody tissue also expands with heat, but timber in use tends to shrink when heated. This apparent contradiction is easily explained. Timber in use always contains a varying quantity of moisture in the cell walls, which, on being heated, is lost to the atmosphere and, as has been previously explained, loss of moisture is accompanied by shrinkage. In consequence, although heat would cause the cell walls to expand, the loss of moisture from the walls results in shrinkage, which more than counteracts any increase in volume caused by the expansion of the woody tissue. In effect, it is not that the expansion of wood substance is low but that shrinkage is high; actually, in linear expansion along the grain, ash is almost identical with cast iron and steel, although the linear expansion of most other species is considerably less; across the grain, the linear expansion of beech is about six times as great as that of iron or steel.

The reaction of timber to heat has an important bearing on its suitability as a fire-resistant material. Because of the relatively high specific heat and poor conductivity of wood, wooden doors are often effective in preventing the spread of a fire for a considerable period. Wooden doors fail when shrinkage causes the different parts, *e.g.*, panels, styles, and mouldings, to pull apart, leaving gaps through which flames can penetrate. Failure through shrinkage usually causes a breakdown of wooden doors long before the flames have been able to penetrate by combustion, or heat by conduction. Metal doors, on the other hand, conduct heat to the opposite side so quickly, and absorb so little heat themselves

in the process, that they tend to pass on a fire from chamber to chamber with great rapidity unless constructed with an insulating core. In a light fire papers filed in a steel cabinet will char and burn whereas under the same conditions those in a wooden cabinet might well come through unharmed. In spite of eventual failure, because of shrinkage, it has been shown that a well-constructed wooden structure is often efficient in *retarding* the progress of a fire: the distinction between *retarding* and *resisting* fire is important — wood is highly combustible, but is not highly inflammable.

ELECTRICAL CONDUCTIVITY

Absolutely dry wood offers practically complete resistance to the passage of an electric current, but the presence of contained moisture renders it a partial conductor. This phenomenon is the basic principle used in the design of electric moisture meters, described on pages 86 and 87. Besides the moisture content of a piece of wood, its density and the species influence its electrical conductivity. For example, lignum vitae, and certain other dense woods, have been used for insulation purposes; they are sometimes impregnated with wax to keep out moisture, thereby maintaining their insulating properties. The small differences in electrical conductivity of different woods of the same density can be explained by attributing such variations to the effect of differences in anatomical structure of different woods and the possible influence of certain inorganic extractives present in some woods.

ACOUSTIC PROPERTIES

The acoustic properties of wood are of importance in musical instruments and in building construction.

The laws of acoustics indicate that the power of conducting or cutting sound is linked with elasticity. Thus a piece of wood, so fixed as to be allowed to vibrate freely, will emit a sound when struck, the pitch of which will depend on the natural frequency of vibration of the piece. This in turn is governed by the density (since density affects elasticity) and dimensions of the piece. Wood, the elasticity of which has been destroyed, as for instance by fungal decay, will give a dull sound when tapped, in contrast to the clear ring of sound wood.

The property of resonance, or of vibrating in sympathy with sound waves, is also possessed by wood by virtue of its elastic properties. The special quality imparted to notes emitted by wood is very pleasing and causes wood to be extensively used in sounding-boards and other parts of musical instruments. Uniformity of texture, which comes from extreme regularity in growth throughout the life of the tree, and freedom from defects, are the essential properties of timber for sounding-boards. Slow-grown spruce, from restricted areas in Czechoslovakia, is perhaps the most famous source of supply of high-grade piano and violin sounding-boards. More recently, balsa has come into prominence for the construction of amplifying chambers of gramophones.

The ability of a material to absorb sound is dependent on its mass, the way in which it is fixed, and on the acoustic properties of the surface of that material, *i.e.*, whether the surface is capable of absorbing or reflecting sound. The cellular nature of wood is such that when timber is fixed so that it cannot easily vibrate, the surface has a deadening effect on sound waves; for this reason wood is valued as a flooring and paving material.

THE HEAT VALUE OF WOOD

Like other organic materials wood is combustible; under suitable conditions it will burn, and its constituents undergo oxidation with the liberation of energy in the form of heat. The fuel value of a timber depends largely on the amount of wood substance in a given volume, *i.e.*, on the density, and on the chemical composition of the wood substance, and on the state of dryness of the wood. As a general rule the denser the timber the higher its potential fuel value, but this may be modified by the presence in the wood of such substances as resin. The fuel value of resin is about twice that of wood substance, and, other things being equal, resinous woods have a higher fuel value than non-resinous timbers. The influence of moisture content will readily be understood; wet wood has a much lower heating value than dry wood of the same species, because much heat is lost in transforming the contained moisture into steam. It is, therefore, anything but economical to use damp firewood: it lasts longer but gives out much less total heat than the same amount of seasoned wood, even on a dry-weight basis.

Another factor influencing the value of wood as a fuel is the ash content. Although this may not affect the heating value to an appreciable extent, for certain commercial purposes the amount of residual ash is an important consideration.

Dense woods burn more slowly, and with less flame, than light woods, which tend to flare up and burn away quickly. Decayed wood has a lower heating value than the same volume of sound wood of the same species. Comparison of relative fuel values of different species presents considerable difficulty, partly because subsidiary merits, such as even, regular burning qualities, and low ash content, are not easily assessed, and partly because the volumetric unit of measurement of firewood — the cord — is capable of wide fluctuations in the actual amount of contained timber, or, in effect, of combustible material. The form of wood, *i.e.*, split billets, logs, or sawn waste, and the method of stacking, result in considerable differences in the fuel value of different cords of wood of the same species: not only may the volume of wood vary, but also its degree of dryness — split billets will dry more rapidly than logs. Comparison with other fuels should be on a dry-weight basis, but even this precaution does not take into consideration the legitimate charge against wood fuel of higher costs for storage and handling of the more bulky commodity. On a dry-weight basis, the heating value of coal is about 1·6 times as great as an equivalent weight of wood, and this figure may be of some value for approximate comparisons. Alternatively, a heat value of 8000 British thermal units per lb. of bone-dry wood may be used as a basis of calculations, suitable allowances being made in comparative costing figures for ease or otherwise of handling, increased cost of storage, ash percentage, and the like. In practice, it is advisable to assume that the efficiency of wood fuel is not 100 per cent. of its British thermal units value but some lesser percentage of this value.

Charcoal is wood fuel in an alternative form: it has a higher fuel value than ordinary wood, both on a volumetric and a weight basis. The advantages of charcoal over firewood as a fuel are largely economic ones, associated with low transport and handling charges per heat unit, the savings more than offsetting cost of manufacture.

No less than 53 per cent. of the total world consumption of wood is as fuel, the largest proportion of which is consumed in a

most wasteful manner in primitive stoves or ovens, and often as open fires on the ground. Burned in this way, it is estimated that 90 per cent. of the fuel value of wood is lost, only 10 per cent. being utilized effectively. These figures take no account of the additional heat value lost by reason of burning green wood, when a considerable amount of the heat generated is absorbed in driving off excess of moisture in the wood. Admittedly, much of the "wood" so consumed would be completely wasted were it not used as firewood, but the prodigious volume of material so involved intensifies the need for tackling this problem realistically. The natural resources of the world are not inexhaustible, and even a small improvement in the manner in which wood is used as fuel could make large quantities of potentially useful material available for other purposes. The development of burning wood in enclosed retorts, to yield producer gas, is discussed in the next section.

THE ENERGY VALUE OF WOOD IN INTERNAL-COMBUSTION ENGINES

Wood and charcoal can be used as a source of producer gas for internal-combustion engines. The choice of timbers for this purpose is a wide one, only mangrove species being less suitable than most, because of their high saline content, which causes corrosion of cylinder walls. For economic reasons, however, the denser timbers are preferable to the less dense ones, and those with a small ash content are more suitable than those with a high ash content. Whenever possible only one species of timber should be used as fuel at a time, thereby ensuring uniform burning and output of producer gas.

In spite of the apparent low cost of the fuel in countries well stocked with forest, producer-gas engines cannot be said to rank as a serious competitor of petrol or Diesel oil engines if a high degree of efficiency in performance is required, and this position is likely to persist so long as the relative cost of the different fuels remains static. The inherent disadvantages of producer-gas engines are three in number: (1) they are of necessity heavier, on a power-weight basis, than petrol engines, (2) they require refuelling more frequently, and (3) the fuel, being bulky, is more expensive to transport and store than petrol or Diesel

oil. In the tropics there is the added difficulty of obtaining firewood or charcoal of only one species in commercial quantities: the mixed composition of the forests makes such selection a practical impossibility, except in mangrove areas, and these timbers, as has been mentioned, are less suitable than most for producer-gas plants. On the other hand, when cheap transport is more important than efficiency in performance, producer-gas engines should not be too readily ignored.

The war years, which deprived many countries of their normal sources of supply of coal and petroleum products, once again focussed attention on producer-gas plants. Apart from generators for mobile vehicles, generators for stationary engines were designed, which undoubtedly functioned efficiently and economically. Even more interesting, was the development of wood-gas stoves for cooking and the heating of domestic hot water. Stoves were produced on a commercial scale in Switzerland, Sweden, and Austria, capable of utilizing — in the form of producer gas — about 80 per cent. of the heat value of wood.

Another approach to the economical utilization of wood as fuel or motive power is the distillation of wood in special retorts to recover the alcohol products, which are similar in character to petrol. This is the specialized field of the wood chemist, involving commercial-size plants of high capital cost, and it must suffice to draw attention here to these derivatives of wood, the commercial exploitation of which could help to solve some of the pressing economic problems of the world today.

PART IV

CONSIDERATIONS INFLUENCING THE UTILIZATION OF WOOD

CHAPTER X

THE SEASONING OF WOOD

THE OBJECTS OF SEASONING TIMBER

Seasoned timber is admitted on all sides to be superior for practically all purposes to unseasoned timber, but the real reasons for the superiority are not always appreciated. It is generally realized that dryness has something to do with the superiority of seasoned timber, but it is also frequently supposed that seasoning is a maturing process that is closely dependent on the time factor. Next to dryness the most commonly acclaimed property of seasoned timber is its freedom from movement. This we have seen from the discussion of variation in moisture content of seasoned timber is not strictly true.

The primary aim in seasoning is to render timber as stable as possible, thereby ensuring that once it is made up into furniture, fittings, etc., movement will be negligible or for practical purposes non-existent; simultaneously, other advantages accrue. Most wood-rotting and all sap-stain fungi can grow in timber only if the moisture content of the wood is above 20 per cent.: hence, seasoning arrests the development of incipient decay in wood and removes the risk of infection of sound timber. Seasoning does not confer immunity from subsequent infection should the moisture content of previously dry wood be raised above the critical minimum, as a result, for example, of prolonged exposure to damp conditions. Several insect pests can live only in green timber, but others do not appear until wood is at least partially seasoned: those that require timber to be green cease their activity as the wood dries out, and in most cases cannot resume the attack even if the moisture content of the timber should subsequently be raised. Reduction in weight of wood accompanies loss of moisture; this is of practical importance as it reduces handling costs, and may effect economies in freight

charges. Reduction in freight charges applies particularly to inland transport, either rail or road, and has led, for example, to cedar shingles being sold in Canada on a moisture-content basis. Seasoning also prepares timber for various "finishing" processes, *e.g.*, painting and polishing, and it is an essential preliminary if good penetration of wood preservatives is sought. Finally, most strength properties increase as timber dries and, although the increases may not in themselves justify the expense of seasoning, they are of more than academic significance.

Certain advantages may be secured by storing seasoned timber for very long periods before it is put into service; these periods are not the two to three years required for initial air seasoning, but periods of twenty to thirty years or more. In this time, dry timber will constantly absorb moisture and swell during wet spells, or lose moisture and shrink during dry periods. Each time there is a change in the moisture-equilibrium conditions the reactions of a piece of wood to such changes become progressively slower. In time it is to be expected that "movement" or "working" would be so retarded that timber exposed only to the slight moisture-equilibrium changes that occur in service indoors would be more stable than timber dried to a particular moisture content for the first time. This, however, is not what is ordinarily understood by air seasoning, and it is not an argument against kiln seasoning, which is superior to air seasoning if carried out intelligently. The special advantages accruing from prolonged storage are secured equally well whether the material is initially air- or kiln-dried.

Drying occurs because of differences in vapour pressure from the centre of a piece of wood outwards. As the surface layers dry, the vapour pressure in these layers falls below the vapour pressure in the wetter wood further in, and a vapour-pressure gradient is built up that is conducive to the movement of moisture from centre to surface. Further drying ("seasoning") is dependent on maintaining a vapour-pressure gradient. This gradient is first established in a freshly sawn piece of wood as a result of loss of water vapour from the surface layers of the piece. The steeper the gradient the more rapidly does seasoning progress, but, in practice, too steep a gradient must be avoided.

Below the fibre saturation point drying is accompanied by shrinkage. The amount of shrinkage that will occur varies with

the species and the degree of dryness attained; it will usually be greater tangentially than radially, and negligible longitudinally. If the tendency of a wood to shrink on drying is high the risk of stresses being set up in the outer layers is great with a steep moisture gradient: the outer layers want to shrink but are restrained by the wetter interior. The outer layers may set in a stretched condition, *i.e.*, case-hardening occurs, or the tissues may be ruptured, *i.e.*, surface checking results.

PRINCIPLES OF SEASONING

Experience has shown that the chief difficulty to be overcome in seasoning timber is the tendency of the outer layers of a piece of wood to dry out more rapidly than the interior. If these layers are allowed to dry much below the fibre saturation point, while the interior is still saturated, stresses are set up, because the shrinkage of the outer layers is restricted. The stresses may attain such magnitude that the tissues in the outer layers of the wood are actually ruptured, and surface splits or checks result. Rupture of the tissues results in fibres separating in the region of the middle lamella, whereas vessel walls break across where two separate members join. The whole art of successful seasoning lies in maintaining a balance between the evaporation of water from the surface of timber and the movement of water from the interior of the wood to the surface. Three factors control water movements in wood: the humidity, the rate of circulation, and the temperature, of the surrounding air. Temperature has a twofold effect: by influencing the relative humidity of the air it governs the rate of evaporation of water from the surface of wood; and it also governs the rate of movement of water outwards in a piece of wood.

Let us see how these three factors interact. The rate of loss of moisture from wood depends on the humidity of the air in immediate contact with the surface layers, and on the dryness of the layers themselves. The rate of movement of water outwards in a piece of wood is dependent on the vapour pressure of the outer layers being lower than the vapour pressure further in, and on the differences in vapour pressure of successive layers not being excessive. If the outer layers are appreciably drier

than the interior greater resistance is offered to the movement of moisture outwards than when differences in vapour pressure, and consequently in moisture content, of successive layers are smaller; in extreme circumstances resistance may be such that diffusion of moisture from the inner layers outwards is brought to a standstill, the moisture in the interior of the wood being sealed in. Resumption of moisture movements in such cases can usually be achieved only by artificial means, *e.g.*, steaming in a kiln. The relative humidity of the atmosphere, and its temperature, are all-important in the seasoning process: the lower the relative humidity of the air the better will it be able to take up moisture from the surface of a piece of wood, and, conversely, wood in contact with saturated air cannot dry at all; alternatively, high temperatures can explain the drying powers of the atmosphere, although its relative humidity is high. At temperatures prevalent in the tropics, namely 80° to 90° F., comparatively high relative humidities, *e.g.*, 70 to 80 per cent., still leave the air with appreciable drying powers because the amount of moisture that air at these high temperatures requires to take up in raising its relative humidity 1 per cent. is so much greater than the amount involved in raising the relative humidity by 1 per cent. at, say, 60° F. This factor in the temperature-humidity relationships of the atmosphere explains why it is possible to air-dry timbers in the humid climates of the tropics to as low moisture contents as those achieved in temperate regions, and in less time. In fact, unless the site conditions of tropical storage sheds are exceptionally unfavourable, the main problem is usually to retard the rate of drying to minimize checking and distortion. At the same time, surface drying is usually not sufficiently rapid to preclude sap-stain discoloration in timbers particularly susceptible to such infestation, *e.g.*, melawis, obeche.

Assuming no temperature changes, the relative humidity of the air increases as moisture is absorbed, and the affinity of the air for further moisture decreases; this, in turn, slows up the drying of the surface layers of wood exposed to such air. When air is absorbing moisture less rapidly, as a result of its relative humidity increasing, differences in moisture content of successive inner layers of wood exposed to such conditions will be less marked, the two factors thus combining to reduce seasoning stresses to a minimum. On the other hand, if the air in contact

with the surface layers of a piece of wood is in constant circulation, its relative humidity may never become sufficiently high to retard the rate of absorption of moisture from these layers, while they, by drying out too quickly, offer greater resistance to the movement of moisture from the interior of the wood, and conditions of maximum stress in the outer layers result.

METHODS

Preliminary seasoning.—Seasoning is sometimes begun before the tree is felled by **girdling** the trunk, *i.e.*, cutting away a strip of bark and wood completely encircling the stem. This is the general practice with teak in Burma, the main purpose being to reduce the weight of the timber so that logs will float. The girdle severs the supply of water from the roots, while, before they die, the leaves exhaust some of the water present in the trunk. The reduction in moisture content secured by girdling is very small, even over a period of a year, but six to twelve months is usually sufficient to ensure that logs of species that just sink when green will float after girdling; teak in Burma is girdled three years before felling.

Timber is sometimes purposely stored in log form to effect preliminary seasoning, although more often than not log storage is a matter of convenience in connection with the maintenance of timber supplies to a mill. In point of fact the loss of moisture from timber in the log is extremely slow, and for practical purposes seasoning may be said to begin only after conversion to boards or planks. There is, however, another aspect of log storage that may be of some practical significance. The parenchymatous tissue in the sapwood remains alive after the tree is felled, until the moisture content of the wood falls below the minimum necessary to sustain life, or until the food material in the cells is consumed. By remaining alive, the parenchymatous tissue uses up the food material essential to sap-stain fungi and certain insects, and the timber is thus rendered immune to infection from these sources.

Two methods of seasoning are in common use: **air**, sometimes called *natural*, and **kiln**, often called *artificial*, seasoning, although in commercial practice a combination of the two will often be more satisfactory and economical. So-called "**water seasoning**" is a misnomer: there can be no loss of moisture so long as timber

remains waterlogged. The hygroscopicity of wood and its subsequent shrinkage may be reduced by "water seasoning", but the benefits are not of sufficient magnitude to be of any commercial value as a method of seasoning. Prolonged storage in water, however, reduces the starch content of the sapwood of species rich in this substance, rendering such timbers less susceptible to powder-post beetle attack. There appears to be some doubt whether it is the reduction in starch content that is of importance, or whether it is the removal of other essential substances that occur in very small quantities in unsoaked wood. In the absence of these other substances timber still rich in starch appears to be immune to powder-post beetle infection. This has been demonstrated with known susceptible timbers: samples soaked in water for three months and subsequently exposed to attack remained immune although their starch content had not been appreciably reduced, whereas other samples from the same consignment that were not previously soaked were heavily infested when exposed to attack.

AIR SEASONING

Air seasoning aims at making the best use of prevailing winds and the sun, while protecting timber from rain. Wind, by circulating the air, prevents it from becoming saturated with moisture absorbed from seasoning timber, and the sun, by raising the temperature of the air, lowers its relative humidity. The combined effect of these two factors is to maintain the drying power of the air. Rain, on the other hand, increases the humidity of the atmosphere, and, as it is accompanied by lower temperatures, reduces the drying power of the air. If at the same time the timber is actually wetted, it may pick up appreciable quantities of moisture. As a general rule, the problem is to accelerate air circulation adequately, although — as explained on page 158 — in the tropics, and with timbers prone to develop seasoning defects, it may be necessary to reduce air circulation and thus slow up the rate of drying. For example, measures are taken to reduce air circulation with a timber such as oak when freshly converted in the warm summer months and, conversely, oak converted in the cool winter months can safely be exposed to greater air circulation.

Control of the climatic factors is best achieved in properly constructed, well-ventilated sheds, but with low quality timber such structures are impracticable on economic grounds. The most efficient shed is, moreover, only effective up to a point: even in weather-proof buildings the relative humidity of the air varies appreciably at different seasons of the year. Control of air circulation, whether in sheds or in the open, is effected by piling the timber in properly constructed stacks, the design of which is the most important consideration in air seasoning. Control of the movement of water in wood is more difficult. Water movement is, of course, affected indirectly by control of air circulation, but additional measures are advisable to compensate for the more rapid movement of moisture along the grain than takes place across it. If the loss of moisture from the ends of a piece of wood is not checked serious stresses are set up that result in bad end-splitting; to minimize this trouble some form of end covering should be adopted. It will be seen, then, that three factors are available for regulating air seasoning; namely, seasoning sheds, correct piling, and end protection of the individual pieces of wood in a stack.

Seasoning sheds.—In its simplest form a seasoning shed may be nothing more elaborate than a large Dutch barn with temporary roofing. On the other hand, it may be a permanent building, consisting of a roof and four walls, the walls being louvred, so that air circulation through the building can be regulated with considerable precision. For softwoods, except of the higher grades, any form of seasoning shed was formerly regarded as prohibitive in cost, but for the more valuable hardwoods seasoning sheds have usually been regarded as essential, and a more or less permanent building with a corrugated-iron roof may often prove more economical in the long run than a purely temporary structure. Today, even the lowest grade of wood represents an appreciable capital investment, and sheds should be regarded as essential; unfortunately, the erection of sheds requires a Building Licence, which is rarely made available for this purpose. In tropical countries some form of shed is very necessary to protect timber against heavy rain and the very strong sun, but because of the intense heat in the middle of the day a corrugated-iron roof should be avoided: thatch, shingles, or rough boarding is better.

Piling.—Piling technique is the most important factor in air seasoning, because such points as the position and orientation of stacks, and their method of construction, largely govern air circulation.

The site of the seasoning yard is usually dictated by such circumstances as the necessity for proximity to the saw-mill, the land available, or the layout of existing buildings. Wherever possible, however, the site should be a naturally well-drained one, sufficiently removed from buildings to guard against the accumulation of stagnant air and/or the creation of air eddies.

The nature of the floor of seasoning sheds or yards is important. The most satisfactory is a good concrete floor, which will not hold moisture, and can be kept clean. A cheaper alternative is well-rammed earth (clay) or cinders. Sawdust is bad as it holds moisture, and results in the circulating air being damp, so that seasoning is retarded, and the development of wood-rotting fungi is encouraged. The floor must be kept clear of rubbish; wood waste left lying about provides opportunities for fungi and insects to breed and spread to sound timber, and such rubbish increases the fire hazard. All wood waste from the saw-mill, and that which inevitably collects in the seasoning shed or yard, should be collected and burned if it cannot be utilized as the raw material of some manufactured wood product, or be sold for some purpose or another. It is not sufficient to collect and dump wood waste in an unused corner of a yard, where it will be equally effective as a breeding-ground, if not so great a fire hazard. The important points in stack-building are the orientation, foundations, spacing, and width of stacks, and the spacing and width of stickers.[1] Two alternative methods of orienting stacks with reference to the passage ways are possible: **endwise**, *i.e.*, with the timber at right angles to the passage ways, and **sidewise**, *i.e.*, with the timber parallel to the passages. Endwise piling makes for ease of inspection and tallying of the stock, but sidewise piling ensures better air circulation from the passage ways. In endwise piling the air is held up by the stickers and can only circulate by way of the narrow alleys between stacks. Economic considerations, and mill layout, however, usually determine the method selected, but where mechanical elevators are used for stack-building sidewise piling is obligatory. If several varieties of timber, requiring different seasoning

[1] See page 164.

periods, are dealt with in the same yard, sidewise piling is more convenient and economical: high handling costs result when one of a series of endwise-piled stacks is required out of turn, because turning space in the passages tends to be restricted, and timber coming out at right angles to the extraction ways may absorb much time in manœuvring. By far the most common failing is to crowd sheds to their maximum capacity, the excuse being made that land values are so high that the fullest use must be made of a firm's storage capacity. This argument overlooks the fact that expelling moisture from wood is inevitably an expensive matter, but quicker air drying that is achieved by not over-filling seasoning sheds may well offset the higher rental costs per cubic foot of throughput because of the saving in fuel when such timber is finally kiln-dried just prior to use. The economics of this argument are worth investigating, although the general application of the theory is likely to have to be deferred until timber is regularly sold on a moisture-content basis.

For the foundations of stacks, baulks of timber are commonly used, but concrete, brick, or even wooden piers, are better, as they offer less resistance to the free circulation of air under a stack. If solid baulks are used they should be at right angles to the alleys. Wood in the foundations should be thoroughly sound and well-seasoned, and, if practicable, it should be treated with creosote or other wood preservative. If species susceptible to powder-post beetle attack are used for the foundations of hardwood stacks the timbers should be absolutely free from sapwood, otherwise infection in the foundations may spread, as drying progresses, to the timber in the stack. This precaution is not of the same importance in stacks of softwood timbers because all softwoods are immune to powder-post beetle attack. For permanent foundations consisting of baulks of wood, it is well worth while considering the possibility of a damp-proof course immediately under the baulks: an excellent method would be to provide concrete footings, and to bed the baulks to these with a bituminous mastic. The height of the foundations should be governed by the nature of the floor: a height of 8 to 12 in. is sufficient with concrete floors, but not less than 18 in. is desirable with earth floors. The foundations of open-air stacks should be sloped to permit of rain running off the top boards or planks in a stack, instead of soaking into the timbers below.

Unless solid baulks of timber, at right angles to the length of the stack, are used, a system of longitudinal members, or piers, with cross pieces or stringers, is necessary. For the cross pieces, metal rails are best as they interfere with air circulation least; they should be at right angles to the length of the stack, and should be covered with strips of wood to prevent the bottom layer of the stacked timber from coming in contact with the metal. If a stack is to be a large one, or if stickers are to be closer together than the spacing of the foundation piers or timber baulks, it is important to distribute the weight evenly over the foundations, and not over the bottom layers of timber in the stack. This can be achieved by a system of bearers and cross pieces, of sufficient strength to carry the weight above, between the foundations and the bottom row of timbers in the stack.

The dimensions of stacks must be kept within certain limits to secure rapid and uniform drying, and to avoid the risk of stagnant air accumulating in the centre of the pile: a cause of unequal drying, and sometimes leading to fungal infection. Twelve feet is recommended as the maximum width for stacks, and two feet as the minimum width of passage ways. Excessive height is to be avoided for similar reasons, and there is the added disadvantage that tall stacks increase handling charges. Sixteen feet is suggested as a reasonable maximum, but unless mechanical elevators are used, or the calls on yard space are particularly pressing, a stack should be under rather than over this height. Wide stacks are to be avoided in countries where termites (white ants) abound: there is a risk that termites may break through the foundations and attack the timber in the pile. Wide stacks make inspection beneath more difficult, and in such circumstances attack may go undetected for a long time.

In practice, the nature of the output of a mill often determines the size of stacks. Where the output is varied as to species, qualities, and sizes the stocks carried of any particular "item" are probably sufficiently small to impose reasonable limitations on the size of stacks. On the other hand, a yard or store confining itself to a few timbers, in two or three sizes, will have to arrange to distribute the out-turn in stacks of suitable dimensions.

Circulation of air through a stack is secured by separating the successive layers of timber by strips of wood known as stickers, the thickness of which regulates the rate of air-flow. The stickers

should be of sound, seasoned timber and, to avoid indentation of boards in the lower part of the pile, not of a harder type than the timber in the stack. The use of softwoods for this purpose is a safeguard against the introduction of powder-post beetles through infected stickers (*vide* also the discussion in para. 3, page 227). When a stack is dismantled the stickers should receive as much consideration as is given to the seasoned timber; they should be collected, bundled, and stored for further use. Proper sticker drill in the seasoning yard is well worth attention: the issue of stickers and their return to stock should be organized as for any other stores. It is common practice to use the lowest grades of wood for stickers, but this is a very short-sighted policy, since stickers are then always lightly regarded, and wastage is high. One-inch boards, piled with 1 in. stickers at 2 feet centres, give a sticker volume of about 4 per cent. of the timber in a stack: if stickers are used only once such wastage will be seen to represent an appreciable additional cost per cubic foot of timber handled at a time when even the lowest grades of wood are worth not less than 10s. per cubic foot sawn. Many years ago one firm bought prime American black walnut for conversion to stickers, and found the outlay well worth while with a sticker life of fifteen years or more.

The most suitable thickness for stickers depends on the thickness of the timber to be seasoned, its drying qualities, and the season of stacking. For thin stock, of species not subject to serious degrade in seasoning, 1½ in. stickers are suitable, but thick planks of species that are inclined to split or surface-check badly may require stickers as thin as ½ in. The time of the year that stacks are built should also be taken into consideration: oak piled for the first time in autumn can safely be stacked with stickers of greater thickness than would be suitable for newly converted oak stacked for the first time in the late spring or summer. To secure rapid drying, the thickest stickers that experience has shown can be used with safety should always be employed; it is doubtful, however, whether stickers more than 2 in. thick secure any further acceleration in the rate of air circulation. Stickers should be no wider than is absolutely necessary, as the area of timber in contact with them is hindered from drying at the same rate as the remainder, and, in certain timbers, such covered portions may become stained Too narrow

stickers, on the other hand, cause indentation and, for this reason, the width should never be less than the thickness, and for really soft timbers it may need to be greater. A maximum of 2 in. in width should, however, suffice for the most easily bruised timber.

The stickers at the ends of a stack should be wider than the remainder and should project about ½ in. beyond the ends of the stacks. By this means a buffer is provided against the rapid circulation of air over the ends of the timber, and a considerable amount of end-splitting is prevented. Furthermore, stickers should project slightly beyond the sides of sidewise-piled stacks to protect the timber from being bumped by traffic in the passage ways.

Stickers impede the circulation of air and, therefore, should not be unnecessarily numerous; on the other hand, an insufficiency of stickers results in the sagging of boards and planks. The distance between stickers depends on the thickness of the stock and its liability to warp; ½ in. boards require stickers 2 to 3 feet apart, but planks of 2 in. and upwards are usually sufficiently supported by stickers 4 to 8 feet apart, the spacing increasing with increase in thickness of the planks.

Plate 46 illustrates the important details of stack construction; it is not, of course, suggested that timbers of such varying thicknesses and classes as those in the "model" stack should be piled together, but the model was assembled to illustrate as many points as possible with the strictly limited amount of timber available to a research laboratory. It may be observed that the stickers are in vertical rows; this arrangement is essential to avoid unequal stresses on the lower layers of timber, which would inevitably result in a considerable amount of bowing. (See also Plate 47.) As far as possible, the timbers in a stack should be of uniform length, but when this is not practicable the longest pieces should be at the bottom; projecting ends must be supported as in Plate 46. Further, in any one row, all timbers must be of the same thickness, otherwise the thicker pieces carry the weight of the whole stack above them. Other points in stack construction are that the top layer of timber, and all projecting ends, should be covered with thin, dry boards, or, if in an open yard, by a raised roof; that thin-dimensional stock should be weighted by laying heavy baulks of seasoned timber on the top of the stacks, to prevent bowing and cupping. Timber should be stacked with

stickers as soon after sawing as possible ; close piling, *i.e.*, without stickers, even for a few days, is a fruitful cause of staining, and, if prolonged, it may result in serious losses from fungal decay.

A special form of piling, often adopted for hardwoods in England and in certain continental countries, is illustrated in Plate 46. In this method, each board is piled in sequence as cut, and the log is sold as a unit. The advantages claimed for this method of piling are that the merchant is not left with narrow widths and defective boards, and, with figured woods, " matched " material is kept together. Incidentally, Plate 47 illustrates many of the " mistakes " discussed in previous paragraphs : the baulks of timber as foundations effectively impede air circulation, the cleats nailed to individual boards will encourage end-splitting in such boards, failure to " weight " the top of the stacks has resulted in distortion of the uppermost boards, and the rubbish lying about is increasing the fire hazard and providing a breeding-ground for insects and fungi.

Timbers liable to discoloration, *e.g.*, sycamore, are frequently seasoned by stacking on end, thereby avoiding the use of stickers; and baulks, sleepers, squares, etc , are usually " self-piled " in various ways, the essential feature of which is that some of the pieces of timber act as stickers A suitable method for rapid drying of sleepers, and short lengths of timber of similar dimensions, is illustrated in Plate 46 item 8 ; long baulks should not be stacked in this manner because of the risk of their bowing.

" Self-piling " is a common practice with softwood timbers in Scandinavian countries ; in this method timbers of the same dimensions as the remainder of the stack are used as stickers, often with no greater distances between the " stickers " than between the pieces of timber in the rows above and below. Unless the pieces used as stickers are short lengths, the stacks are too wide to secure a uniform rate of drying in the whole pile. When used for boards stacked flat, the method is obviously inferior to piling with proper stickers. But planks are frequently piled on their narrow face, the distance between the rows being the width of the planks, *i.e.*, one row of planks is laid flat, the next on their narrow faces, and the succeeding row flat, and so on. In this way the distance between the rows may be 6, 7, 8, or 9 in., and, if the planks are only 2 to 3 in. thick, a relatively small area of timber in the stack is covered up by other green material. Such

Air Seasoning of Timber

Points illustrated in Plate 46

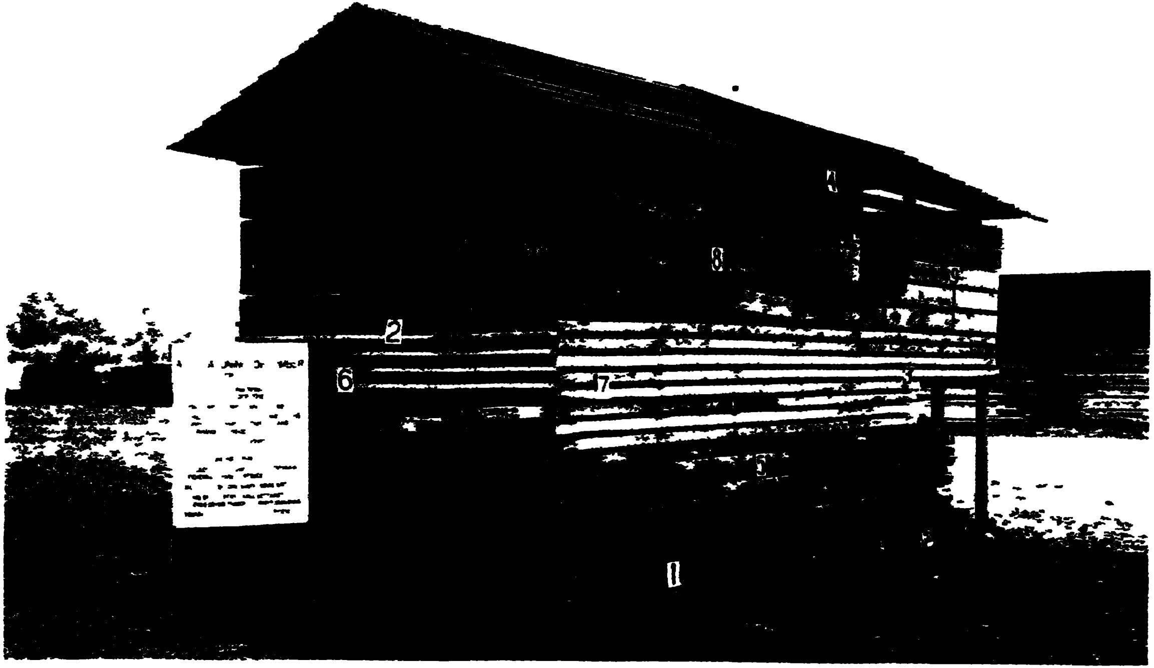
1. Level foundations which raise the pile well off the ground.
2. Stack not more than 6 ft wide.
3. Piling sticks (=stickers) in vertical lines and the support of short lengths and overhanging pieces.
4. Weather-tight sectioned roof.
5. 2 in. oak with ½ in. sticks to reduce rate of drying and prevent checking.
6. 2 in. beech with flush stickers, overhanging stickers and coatings to reduce end-checking.
7. Method of building sample board into pile.
8. Piling of sleepers and large-sectioned stock of free-drying timber for rapid seasoning.
9. Squares piled in stick and self-crossed.

---

an arrangement ensures rapid drying of the surface of the timber, a very necessary condition if "blue-stain" is to be avoided in European redwood, but it is too drastic for many timbers and might give rise to serious surface-checking.

If timber has to be stored on a building site for any but a very short period it should be built into temporary, roofed stacks. This is equally important, whether the timber is partially or fully seasoned when delivered. If partially seasoned, piling with stickers will ensure that some seasoning will occur on the site; that is, the best use will have been made of the interval between delivery and use. If the timber is seasoned when received it is imperative to keep it covered so that it will not become wetter before it is required; joinery should not only be under cover, it should be stored in a weather-proof shed.

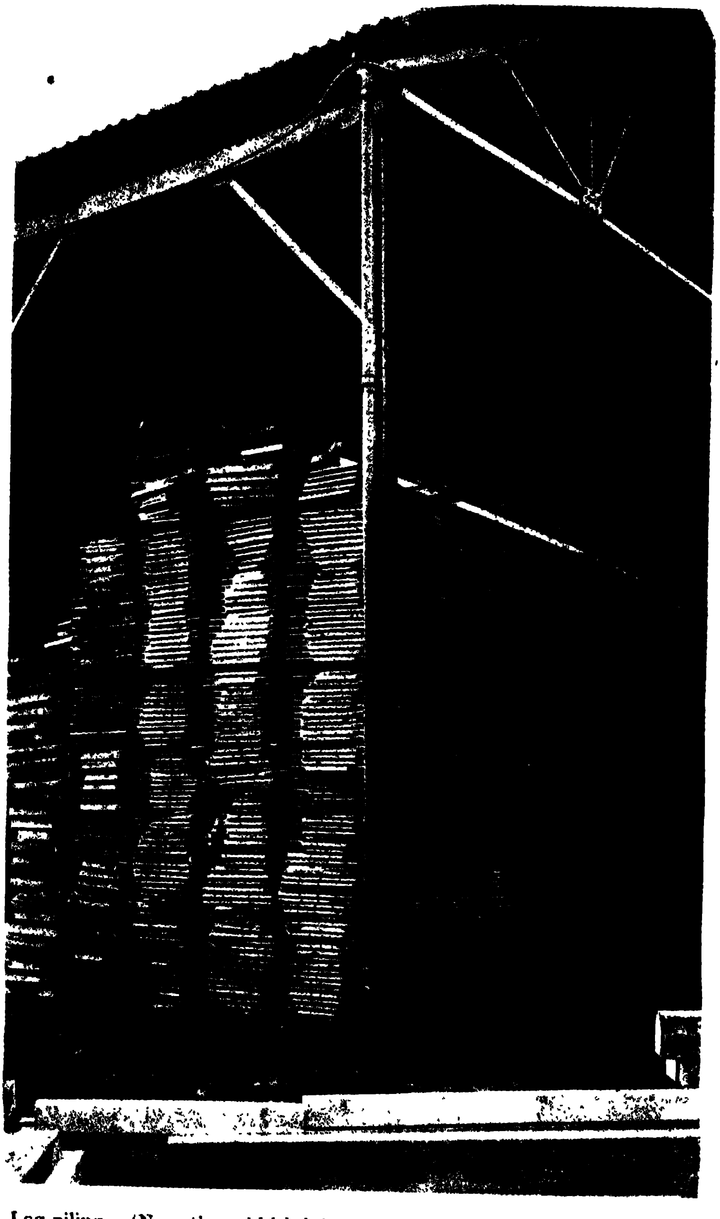
It is common practice to close-pile softwoods on arrival in this country, and serious consequences have not resulted in the past from this practice, at least with European redwood. It has, however, been generally recognized that deck cargo that has become wet in transit cannot be so treated — it must be properly stacked until dry. Prior to 1932 close-piling was permissible because most of the imported timber came from northern Europe, and



Stack showing the various points of good piling technique (Note that the surrounds of the stack are free from rubbish compare this with the condition of the yard illustrated in Plate 47)

Photo by F P R L Princes Risborough

PLATE 47



Log piling. (N the rubbish lying about ; this is a bad feature of the shed illustrated)

had been stacked for some time before shipment: it was more or less air dry. Piling prior to shipment is not usual on the Pacific Coast: the timber, unless kiln-dried, tends to be shipped as cut, which may be the day of shipment. Such green timber may escape harm in transit, but unless properly stickered on arrival in this country it may well develop dote over here, and it certainly will not dry out if close-piled (see also the discussion of dote on pages 212 and 213)

End protection.—End protection is provided by coatings of various, more or less waterproof, substances, or by strips of wood or metal nailed to the ends of timber. Strips or cleats of wood are thoroughly bad for any timbers but thick planks, because the small longitudinal shrinkage of the strip is opposed to the much greater transverse shrinkage of the timber, with the result that shrinkage is restricted between the points of attachment of the strip, and end-splits frequently develop in the piece of wood. Splitting will almost invariably occur in timber up to 1 in. thick if wooden cleats are used, but planks 3 in. or more in thickness may not suffer any harm unless incipient splits are present before the cleats are attached; in these circumstances, however, the cleats are likely to be ineffective in preventing the splits from developing. If end protection is provided by a thin strip of metal, *e g.*, hoop iron, the metal buckles concertina-fashion as the baulk shrinks and end-splitting may be avoided S-shaped pieces of iron, driven into the ends of baulks of timber, are effective in preventing the development of splits that have already occurred, or in reducing the amount of splitting that would occur were no protective measures taken. More satisfactory than wooden cleats or iron ones, is the use of an end-coating, the essential qualities of which are impermeability to water and air, a semi-liquid state to permit of its being applied with a brush, and a capacity to harden on exposure so that it will set and not flake off when the timber is roughly handled. Many substances and mixtures fulfil these conditions so that choice is mainly one of expediency. Wax is an obvious possibility, but cost, and the necessity of having to apply it hot, make it unsuitable. The United States Forest Products Laboratory recommends a mixture of one part asbestine and one part barytes to two parts of hardened gloss oil; a gallon of the preparation being sufficient for 100 square feet. A very successful mixture consists of finely powdered,

unburnt brick clay and ground dammar (a resin compound soluble in petroleum spirits) in equal proportions, with sufficient paraffin to permit of spreading the mixture. The proportion of clay may be increased to about 55 per cent. to reduce the cost of the preparation. Clay or chalk, mixed with dung as a spreading medium, has also been used, but fine mud without a binding medium flakes off too easily to be of value. Various proprietary petroleum waxes are available on the market; they usually have the advantage over ordinary waxes, in that they can be applied cold, and they are more or less transparent. Sheets of plywood nailed over the ends of a stack to the projecting stickers are a cheap compromise, but they interfere with the circulation of air along the stack and may slow down the seasoning process too much for all but the more refractory timbers.

KILN SEASONING

Kiln drying is effected in a closed chamber, providing maximum control of air circulation, humidity, and temperature. In consequence, drying can be regulated so that shrinkage occurs with the minimum of degrade, and lower moisture contents can be reached than are possible with air seasoning. The great advantages of kiln seasoning are its rapidity, adaptability, and precision. It also ensures a dependable supply of seasoned timber at any season of the year; and it is the only way that timber can be conditioned for interior use requiring lower equilibrium moisture contents than those prevailing out-of-doors, or in unheated sheds.

There are other advantages gained by kiln drying. In properly operated kilns, every piece of timber in a kiln load can be dried to a uniform moisture content throughout. Moreover, the drying process also sterilizes the timber: the temperatures used, and the humidities maintained in a kiln, are lethal to any insect or fungus present in the timber when placed in a kiln. Such sterilization does not, of course, protect the dried timber against fresh infestation after removal from the kiln. Further, the resins or gums in certain woods are to a large extent set or hardened in kiln drying, so that the risk of subsequent "bleeding" from finished surfaces is reduced. On the other hand, errors in the technique of kiln operation may have serious consequences: seasoning degrade

can be magnified, and whole consignments of timber hopelessly spoiled, by improper kiln drying.

It is necessary to regulate kiln drying to suit circumstances: different timbers and dimensions of stock require drying at different rates. As a general rule, softwoods can withstand more drastic drying conditions than hardwoods, thin boards than thick planks, and partially dry stock than green timber. There are limitations as to the dimensions that can be kiln-seasoned economically: unless timber is previously treated with certain chemicals, so-called salt seasoning or chemical seasoning (*vide* page 192), kiln drying is only suitable for material up to about 3 in. thick: above this figure the rate of drying would have to be so slow, to avoid serious seasoning degrade, that the method would be altogether too expensive. On the other hand, the occasions when large-sized timbers are required uniformly dried to low moisture contents of around 12 per cent. are extremely few so that restriction to the smaller maximum dimensions suggested does not really impose limitations of practical commercial importance.

In the past, stnadard drying schedules have often been employed, irrespective of the species, dimensions, or condition of the timber to be seasoned, and, too often, kilns have been little better than hot ovens. In such circumstances kiln drying can be thoroughly unsatisfactory, resulting in serious damage to the timber. Such malpractices are undoubtedly at the root of many objections still levelled against kiln drying, whereas extensive tests show that, if properly carried out, kiln seasoning is not only as successful as air seasoning, but in many respects is superior. For reasons of economy, it is common practice to air-dry timber initially, and to complete drying to the required final moisture content in a kiln. Provided air drying is done properly, the combination of air and kiln drying is not open to any objections, and should prove much more economical than kiln drying from green: 1-in. oak, kiln-dried from green, will have to occupy a kiln from 5 to 6 weeks if degrade in drying is to be avoided, and throughout this time consumption of fuel and power is incurred. The same timber, first air-dried to just below the fibre saturation point, should not require to be in a kiln for more than half the period.

A kiln consists of some form of more or less air-tight shed,

fitted with heating apparatus, a supply of water or steam sprays, and, in some types of kilns, artificial means of accelerating air circulation. One of the greatest problems in kiln construction is the reduction of heat losses to a minimum. To this end cavity walls of brick or tile are generally used, and the interior surfaces are painted with some water-proofing substance. The doors are of wood or metal of several designs that aim at securing a tight fit.

The usual method of supplying heat to kilns is by a system of steam-heated coils over which the air passes before circulating through the stacks of timber. Other methods of heating could be used but steam is particularly suitable as it is easily regulated, and in many saw-mills it is available from the burning of wood waste. Special types of furnace-heated kilns have been developed in recent years ; these will be discussed after the more conventional types of kilns have been described.

The humidity of the air can be controlled by regulating the temperature, by admitting water or water vapour, or by changing the air through removal of saturated air from the kiln and replacing it with fresh air from the outside. In practice the manipulation of temperature alone is seldom sufficient, and a system of water or steam sprays, and inlet and outlet air ducts, are installed. The circulation of air is secured by "natural-draught" or mechanical means. The former method is dependent on temperature differences at different levels in the kiln, which cause air currents to be set up. Forced circulation is obtained by means of fans or blowers. Natural-draught circulation is sometimes further stimulated by the suitable arrangement of the steam or water sprays.

In theory the air in a kiln can be used indefinitely, if there is some means of de-humidifying it after it has passed through the timber. In practice some of the moisture is removed from the air by condensation on the walls of the kiln, but it is usual to arrange for a portion of the moisture-laden air to be drawn off and replaced by an equivalent amount of fresh air from the outside. The escape of used, humid air, and the introduction of fresh, relatively dry air, is usually designed to take place through special outlet and inlet channels, but a certain amount of interchange occurs as a result of natural leakage.

The rate of drying in different parts of a kiln varies, because the temperature of the air and its relative humidity vary at

different levels, and arrangements have to be made to counteract this as far as possible. One method is to increase the rate of circulation, so that there is less opportunity for the air to become saturated before it has passed through the stack. Where artificial means of accelerating air circulation are not installed the same effect can be obtained by keeping down the size of the stacks of timber, or alternatively, the direction of circulation may be reversed by means of a double set of outlet and inlet ports, coils, and sprays.

It is important to follow the conditions of the air in a kiln closely during a run, and also the progress of drying in the timber. The first can be done by means of wet and dry bulb thermometers (hygrometers) (Fig. 30) suitably placed in the kiln, and illuminated, so that they can be read from outside the kiln. With readings of the two thermometers, the relative humidity of the air in a kiln is found by reference to appropriate tables or charts. Self-recording instruments are sometimes used in place of simple mercury thermometers; these incorporate inked pens, and charts (graph paper so ruled that the relative humidity is read direct). Such instruments are an essential part of a fully automatically operated kiln, and they provide a very useful record of conditions in a kiln throughout the entire run, but unless very carefully maintained — and they are delicate instruments — they have certain disadvantages in comparison with the simple mercury-in-glass thermometers. They are costly, relatively sluggish, and easily damaged by rough handling of the pens when changing the charts. Precautions are necessary in siting hygrometers in a kiln to ensure that they give a correct picture of the condition of the circulating air. A minimum of two instruments is essential, so placed that the state of the air, both as it enters and leaves the pile of timber, can be read. When only one instrument is used, control of the kiln is not infrequently determined from the condition of the air leaving the timber, when serious mistakes can be made. Such air will have a lower temperature and higher relative humidity than fresh air admitted into the kiln and heated before circulation. If the conditions of the moment call for air of the temperature and humidity of that leaving the timber, the actual air circulated is liable to be too warm and too dry, causing too rapid drying, with the risk of serious seasoning degrade. Instruments must be at least 6 in. from any wall so that they

are in the path of the main air-flow. To enable hygrometers inside the kiln to be read from the outside port-holes should be provided in the end walls of a kiln, and electric lighting for illumination of the instruments: frequent opening of kilns to read instruments would be extremely wasteful of steam. Low-powered field glasses or opera glasses should be used for taking

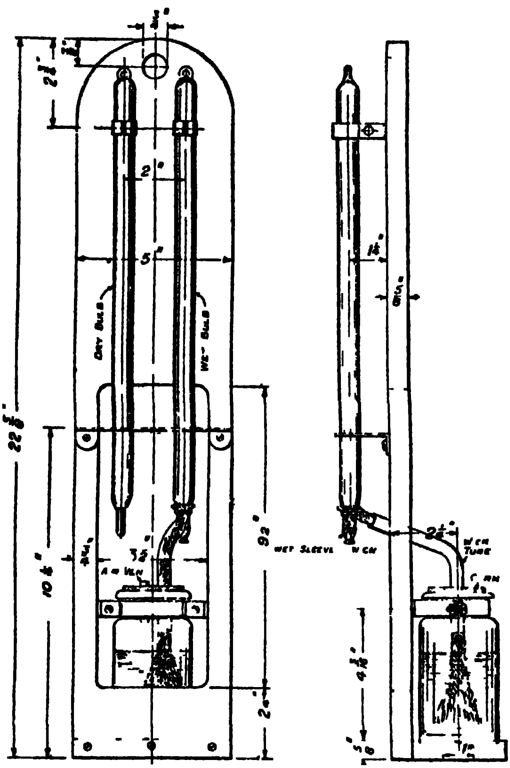


FIG 30.—A standard type of wet and dry bulb thermometer

By courtesy of the Director, F.P R L, Princes Risborough

readings. Thermometers graduated in degrees centigrade have been found rather easier to read than Fahrenheit thormometers. All hygrometers require maintaining in good order; with the simple mercury-in-glass type, this merely involves maintaining the water level in the receptacle, and the syphoning wick, in perfect condition. Distilled water should be used, and the calibration of the instruments should be checked annually.

Progress of drying in the timber should be followed by means

of "test" or "sample boards". At the commencement of a run, the moisture content of the parcel as a whole should be determined from a sufficient number of samples by the oven-dry method described on page 84. The boards or planks from which the samples are taken also serve as "sample boards" for following the progress of drying. After the moisture-content samples have been cut from either end the remaining length of each board should be at least five feet. The sample boards should be immediately weighed and returned to the pile, but so distributed that they will provide a picture of the progress of drying in the whole consignment. The stickers above the boards are notched so that the boards can easily be withdrawn for periodical weighing, and then be replaced. The weights of the boards, at the selected final moisture content, are arrived at by calculation, as explained on page 84. Intermediate weighings give, by calculation, the moisture contents of the moment, and the progress of drying is, therefore, followed closely. The drying schedule can be modified according to whether it is revealed that drying is too rapid or too slow.

In spite of reasonable care it is possible for drying stresses to be set up in the course of a kiln run, sufficiently serious to cause case-hardening or honey-combing,[1] if not actual visible splits or checks. When such stresses are suspected, and also as part of the routine study of drying progress, the consignment should be tested for such stresses. For this purpose, strips or prongs from test pieces cut from the sample boards are used, *vide* Fig. 31. Cross sections ½ in. thick, cut 9 in. or more from the ends of the sample boards, provide the test pieces. For the "strip" test pieces the cross sections are cut into four equal strips, parallel to the original surfaces of the boards, as in Fig. 31, *a*. Alternatively, the outer strips can provide the prong-shaped test pieces by cutting away the middle portion to within 1 in. of one end, as in Fig. 31, *b*. A study of the behaviour of the strips or prongs will indicate the nature and extent of the drying stresses. In the early stages of drying, tension stresses tend to be set up in the outer layers of the wood. At this stage the strips and prongs will immediately curve outwards when cut, as in Fig. 31 (ii). When the samples are allowed to dry for 12 to 24 hours, to a uniform moisture content, the slightly wetter inner faces of the strips or prongs

[1] For definitions of these terms see page 205.

will shrink more than the outer faces, and, if permanent stresses have occurred, the strips or prongs will eventually bend inwards, as in Fig. 31 (iii). At a later stage in drying, the behaviour of the test pieces is different. By this time the stresses become reversed in the wood, and the core is in tension while the outer layers are in compression. Test pieces cut from boards in this condition will immediately curve inwards, and, when allowed to dry to a uniform moisture content, the extent of curvature will be increased. When no permanent set has occurred the strips or

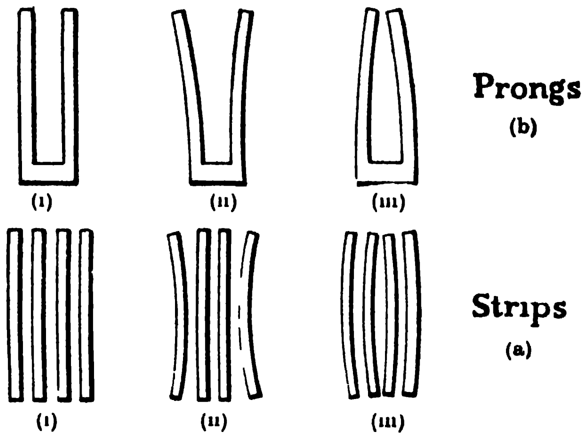


FIG. 31.—Prongs or strips used in testing for drying stresses

By courtesy of the Director, F P R L, Princes Risborough

prongs will become parallel, as in Fig. 31 (i), on reaching a uniform moisture content, that is, after 12 to 24 hours' exposure to normal atmospheric conditions. If tests reveal that serious drying stresses have developed, the drying schedule must be modified to relieve these stresses; this aspect is discussed in the section on kiln operation.

It was necessary to dilate on the importance of correct piling technique in air seasoning; correct and careful piling is of no less importance in kiln seasoning, and the trouble taken is always justified because the appearance and quality of the load at the end of a run will be superior, compared with a poorly piled load. With very few exceptions, piles must be built with stickers as for air seasoning — the exceptions are certain classes of dimension stock. The stickers should be selected from clean, dry timber,

and finished 1 in. by 1 in., or for thin boards 1 in. by ¾ in. Softwoods, except larch, and hardwoods not inclined to warp of 2 in. and upwards in thickness, should have stickers spaced at 3 feet centres; for boards, *i.e.*, material less than 2 in. thick, the spacing should be reduced to 2 feet. Two-inch material of larch, beech, birch, and other timbers that tend to warp appreciably in drying, should have stickers spaced at 2 feet centres, and for boards of these species the spacing should be reduced to 18 in. centres. Still more refractory timbers, *e.g.*, elm, should be piled with stickers at 12 in. centres.

The same precautions must be taken regarding the alignment of stickers in vertical rows as in air seasoning, and loads must be distributed to the foundations by means of a system of cross stringers and bearers when the stickers are spaced closer together than the distance between the main supports of a stack. Special supports must be provided for long boards that overhang the ends of a stack. Stacks of boards may be weighted to advantage, to reduce distortion in the upper rows of a stack; concrete slabs are suitable, but ferrous metal weights must not be used with timbers such as oak and chestnut because the tannin in these woods may lead to serious staining when brought in contact with iron in a humid atmosphere.

Construction of kilns.—Concrete floors and footings, with provision of drainage for the floor, are recommended. Eleven-inch brick cavity-wall construction is probably the most economical form of walling; slight ventilation of the cavity is desirable. Reinforced concrete, with provision for thermal expansion, is suggested for the roof of the kiln. The roof of a double-stack kiln will require supporting on steel joists. An independent light roof to protect the kiln, air outlets, motor, etc., from the weather, and also to permit of additional insulation of the kiln roof with sand or sawdust, is strongly advised.

Doors can be a serious source of heat loss; side-hung doors, with heavy stiles and rails, have been proved unsatisfactory. The authorities at Princes Risborough recommend a centre-hung door, constructed with a timber frame, an inner sheet-metal face, protected by paint from corrosion, with an air gap for insulation between this and the outer face of resin-bonded or other waterproof plywood or matchboarding. Further provision against heat loss is secured by ¾ in. wide felt strips between doors and jambs,

with clamps around the edges so that the door can be pulled up hard against the jamb.

Of the two types of forced-draught kilns, the external-fan kiln is more compact than the internal-fan type, and the regulating apparatus is particularly accessible, but the air is admitted and withdrawn at the same point, so that unless baffles and dampers are carefully arranged there is a risk of the air circulation short-circuiting.

Type of kiln.—There are two main types of timber-drying kilns, namely, progressive and compartment kilns: the former are almost always operated by the "natural-draught" method, but the latter may be natural- or "forced-draught" operated.

Progressive kilns.—In progressive kilns green timber is admitted at one end and moved gradually to the other, where it emerges dry. The air flows in the opposite direction to the movement of the timber, so that the material that has been longest in the kiln receives the hottest and driest air. In passing through the piles of timber the air absorbs moisture, which increases its relative humidity and lowers its temperature, so that at the loading end the wet timber comes in contact with relatively cool, humid air. The severest drying conditions are, therefore, at the exit end, where the timber is best able to accommodate itself to them, and the mildest at the loading end, where the timber is least able to stand up to rapid drying. After circulation through the length of the kiln, part of the air is discharged into the atmosphere, and the remainder returns below the floor of the kiln to be re-circulated. Fresh air is admitted at suitable openings to compensate for the amount discharged, and this, mixed with the returning cool air, is heated prior to circulation through the timber. Fig. 32 illustrates the principal points in the design and mode of operation of a natural-draught, progressive kiln.

The uses of progressive kilns are limited since their successful operation depends on a steady supply of timber of the same species and dimensions. The reason for this is that the drying conditions cannot be modified as each new load is added, and while the kiln still contains partially dried loads of a particular type. In addition to lack of flexibility, progressive kilns cannot be regulated with great precision, and this renders them unsuitable for timbers that are difficult to season. Further, as the

main air-flow is longitudinal the timber should be piled at right angles to the length of the kiln (to ensure uniform drying) and this restricts progressive kilns to short stock unless kilns of great width are provided. The advantages of progressive kilns are held to be that, once placed in efficient operation, they require less skill to run, and the output is more or less continuous, compared with compartment kilns.

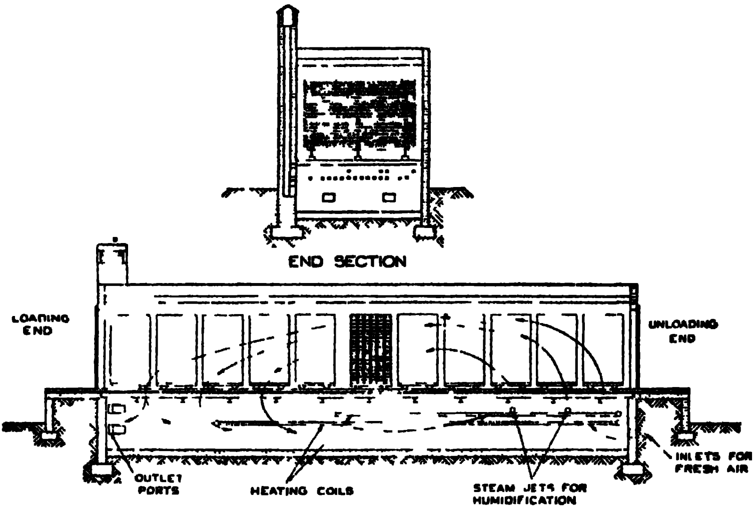


FIG. 32 —Progressive kiln

By courtesy of the Director, F P R L, Princes Risborough

Compartment kilns.—A compartment kiln, like a progressive kiln, consists of a closed chamber, but it differs in operation in that the timber remains in the same position in the kiln throughout the drying period, the temperature and humidity of the circulating air being constantly changed. Such kilns may be operated by the natural-draught or the forced-draught methods. The air may be circulated cross-wise from top to bottom of the kiln, or *vice versa*, or from end to end; and the circulation may be reversible. The timber may be stacked on edge, when the main circulation is usually up through the stack and down the sides of the kiln · or flat-piled, when the circulation is up one side, across the stack, and down the other side. Flat piling, the more common method, is sometimes arranged with a central flue, the air travelling up the flue and circulating to either side.

Conditions at the commencement of a run are mild; that is, the relative humidity of the air in circulation is high and its temperature is low. As drying proceeds the temperature is raised and the humidity is reduced, and, as a result, the drying conditions become more severe, but are kept within bounds to prevent degrade of the timber.

The great merit of compartment kilns is their flexibility in operation, coupled with the fact that they can be designed to give precision of control. Flexibility is desirable when the out-turn of a mill is constantly changing, both in species and dimensions of stock; and maximum control of drying conditions is essential for the successful drying of difficult timbers. In effect, compartment kilns are to be preferred to progressive kilns in all but special circumstances; in practice the special circumstances are mills producing continuous supplies of a single timber, of one thickness.

Fig. 33 illustrates a natural-draught compartment kiln, with a central flue in which steam-jet humidifiers assist air circulation to some extent. Fresh air is admitted in the basement, and, after passing over heating coils, circulates *via* grids running the length of the kiln between the stacks of timber. The air is humidified at the floor level and it then rises, passing through both stacks to fall between the timber and the walls of the kiln. Some of the used air escapes at floor level *via* the chimneys, and the remainder falls to the basement where it mixes with fresh air before re-circulation.

This particular type of compartment kiln is not suitable for very wet timber: the circulation is slow and uncertain, and it is difficult to regulate, but the kiln is simple to construct, there is little about it to get out of order, and it can be made reasonably economical in heat and steam. This type of kiln is suitable for drying partially-seasoned stock, and for re-drying stock that has taken up moisture in the course of manufacture.

Modifications in design of natural-draught kilns have been evolved with a view to improving air circulation and providing facilities for more precise control. For example, kilns are sometimes fitted with cooling pipes through which cold water circulates. These pipes condense the moisture absorbed from the timber by the circulating air and, since removal of this moisture is continuous, more rapid circulation of air is secured than is possible

when de-humidifying of the air in a kiln depends on admission of fresh air from the outside by means of hand-operated vents. Another type of kiln is the water-spray compartment kiln designed by Mr. H. D. Tiemann of the U.S. Forest Products Laboratory. In this type, water sprays are arranged in rows along the side walls of the kiln and heated air passes through them, and is cooled in the process until it reaches a state of saturation. The

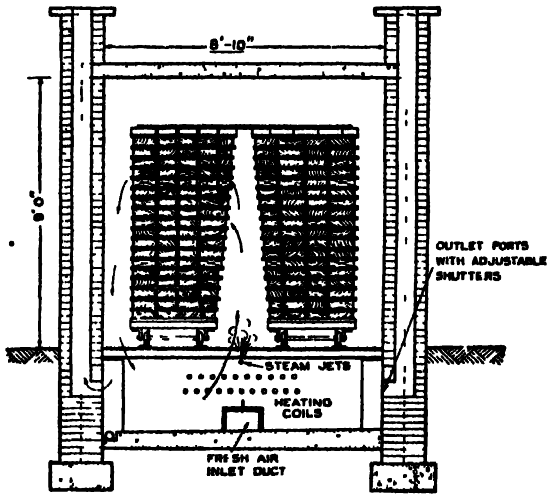


FIG. 33.—Natural-draught compartment kiln
By courtesy of the Director, F P R L, Princes Risborough

saturated air is then re-heated, to reduce its relative humidity to any required figure, before circulation through the timber; by this means the condition of the air in circulation can be precisely controlled. Water-spray compartment kilns are, however, complicated in design, and in operation, and they consume appreciable supplies of water and heat; greater precision in control can be secured with a good type of forced-draught kiln, and such kilns can be quite simple in design, besides being easier to operate than the water-spray type.

Forced-draught kilns may be of the external-fan or internal-fan type. In the external-fan kiln the air is heated, humidified, and set in motion by apparatus located outside the kiln, whereas in the internal-fan type the heating, humidifying, and circulating apparatus is situated inside the kiln, either in the roof or base-

ment. Figs. 34 and 35 illustrate an internal-fan kiln (double-stack pattern), the design of which was evolved at the Forest Products Research Laboratory, Princes Risborough. The fans, heating coils, steam sprays, and used-air outlets, are situated in the roof, and the fresh air is admitted at floor level. This arrangement makes for economy in construction over basement-type kilns, while providing reasonable accessibility, immunity from flooding, and ease of loading. The kiln illustrated in Figs. 34 and 35 is undoubtedly one of the most efficient and economical types of kiln at present available; it embodies the results of extensive research and practical experience in operation of overhead, internal-fan kilns, having been developed at the laboratory from earlier prototypes. It probably offers more uniform air circulation than any kiln of this size yet designed, and it provides the maximum timber accommodation for a minimum of standard engineering components.

The width of stacks in the double-stack kiln should be about 5 ft 6 in. and should not exceed 6 feet. Allowing space for two stacks, a 2 feet centre corridor (the diameter of the fans), and inlet and outlet ducts, the maximum width of the kiln is 17 feet. The height from the bottom of the timber stack to the false ceiling of the kiln should not exceed 8 feet. If the volume of timber to be dried does not fill the kiln the unused space must be blanketed off with curtains to prevent the circulating air from short-circuiting over the tops of the stacks.

Fans are required at intervals of 5 feet, and 2 feet is required between the ends of the stacks and the kiln doors. These requirements impose a minimum economical length of 12 feet, and where this dimension provides too large a kiln for a mill's requirements some other pattern is likely to be more economical.

For mills requiring kilns of smaller capacity than the one described above — and in this country where many thicknesses and species are handled by one mill this will often be the case — a smaller, cross-shaft, overhead fan kiln has been designed at the Forest Products Research Laboratory, *vide* Fig. 36. The aim has been to provide a highly efficient kiln with the minimum of metal constructional parts, as these call for skilled labour in erection. By substituting 3 feet diameter fans for the 2 feet diameter fans used in the double-stack kiln, and a completely reversible system of air circulation, it has been possible to increase

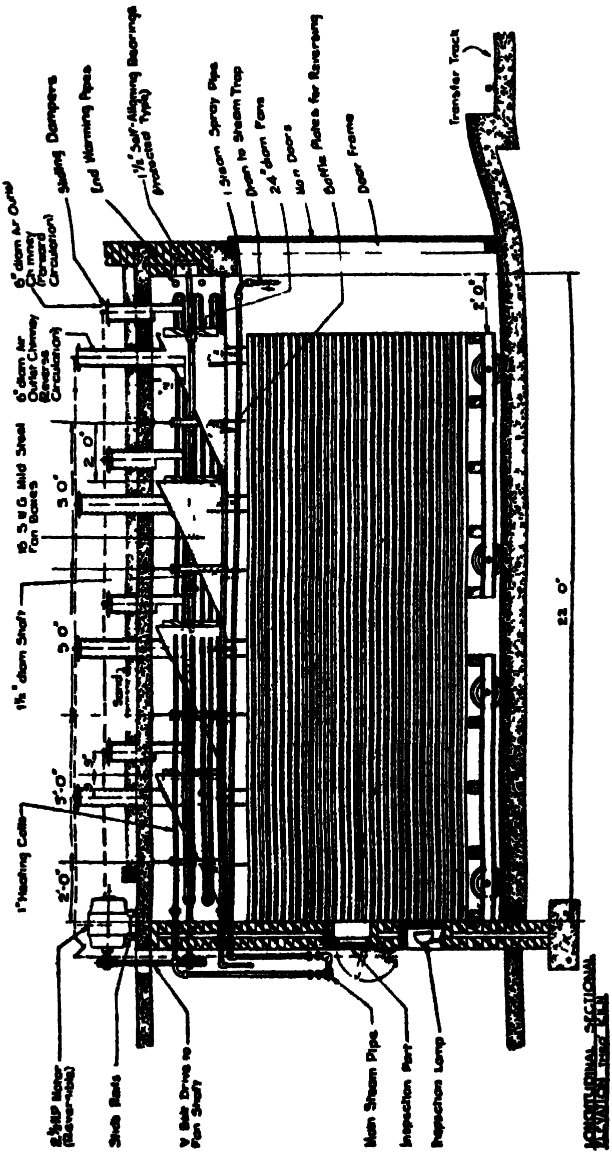


FIG. 34.—Internal-fan kiln (double-stack pattern)
By courtesy of the Director, F.P.R.L., Princes Risborough

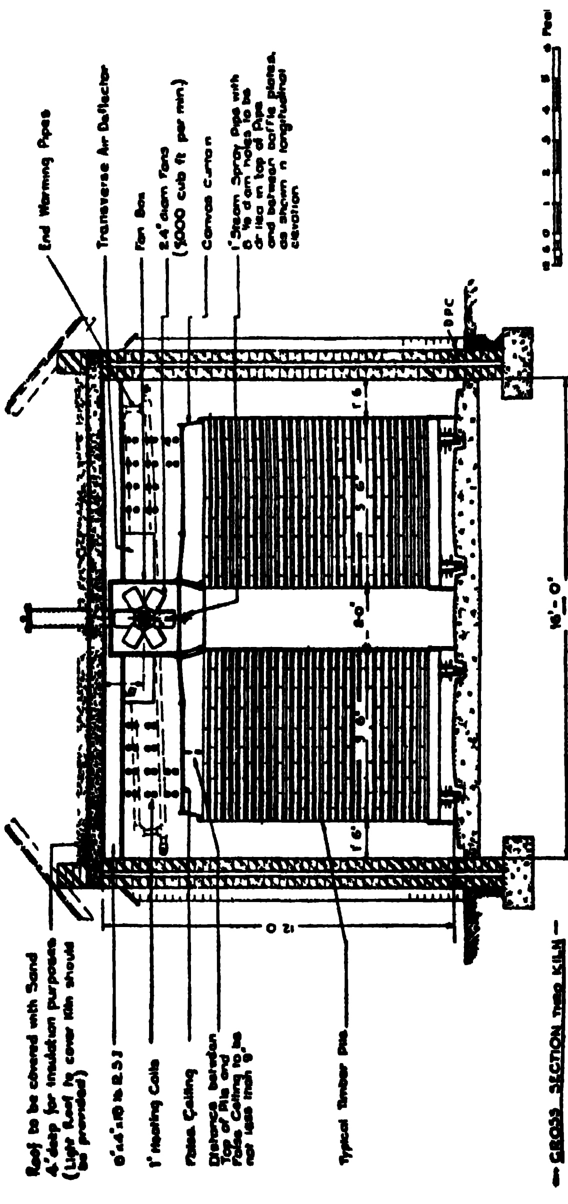


FIG. 35.—Internal-fan kiln; section view of Fig. 34

By courtesy of the Director, F.P.R.L, Princes Risborough

the width of the pile to 7 feet, and yet ensure uniform drying of the whole load. Adding the 18 in. for inlet and outlet ducts on either side, the maximum width of the kiln is 10 feet. The height from the bottom of the stack to the false ceiling is 8 ft 6 in., and a clearance of 9 in. between the top of the pile and the ceiling is recommended. The whole length of the kiln may be utilized for timber, but in this case access doors to the side ducts should be provided. The length of the kiln can vary within limits to meet a mill's needs, so long as adequate provision is made for drainage.

Considerable latitude in the selection and design of the heating arrangements is possible; ordinary 1 in. steam piping and fittings have been found quite satisfactory. Details depend on the timbers to be dried, and the maximum temperatures likely to be required: these and other points are set out in *Forest Products Research Laboratory* leaflet No. 18.

Forced-draught compartment kilns have the great merit of adaptability for drying any kind of timber in any condition, and they can be regulated with precision to suit all circumstances. Such kilns, however, are more costly to build, and complicated to construct and operate, than natural-draught kilns.

Furnace-heated kilns.—The progressive and compartment kilns so far described depend on steam for heating. several attempts have been made to utilize the heat from burning wood-waste direct to dry timber, and furnace-heated kilns, as they may conveniently be called, of proprietary manufacture have been on the market for some years. In their simplest form, reliance is placed on moisture expelled from the drying wood to provide suitable humidity conditions in the kiln, and not unnaturally this has often proved unsatisfactory for drying refractory timbers. The use of wood waste for fuel, and the elimination of a boiler and steam piping, are, however, obviously attractive points in a simple, inexpensive kiln. For these reasons attention was paid to the design of furnace-heated kilns in the war years both at the Forest Research Institute, Dehra Dun, and at the Forest Products Research Laboratory, Princes Risborough. A kiln evolved at the latter laboratory is illustrated in Figs. 37 and 38. This follows closely the design of the single-stack compartment kiln described above; it is 20 feet long, and accommodates a trolley-loaded pile of timber 6 feet wide. Air circulation is

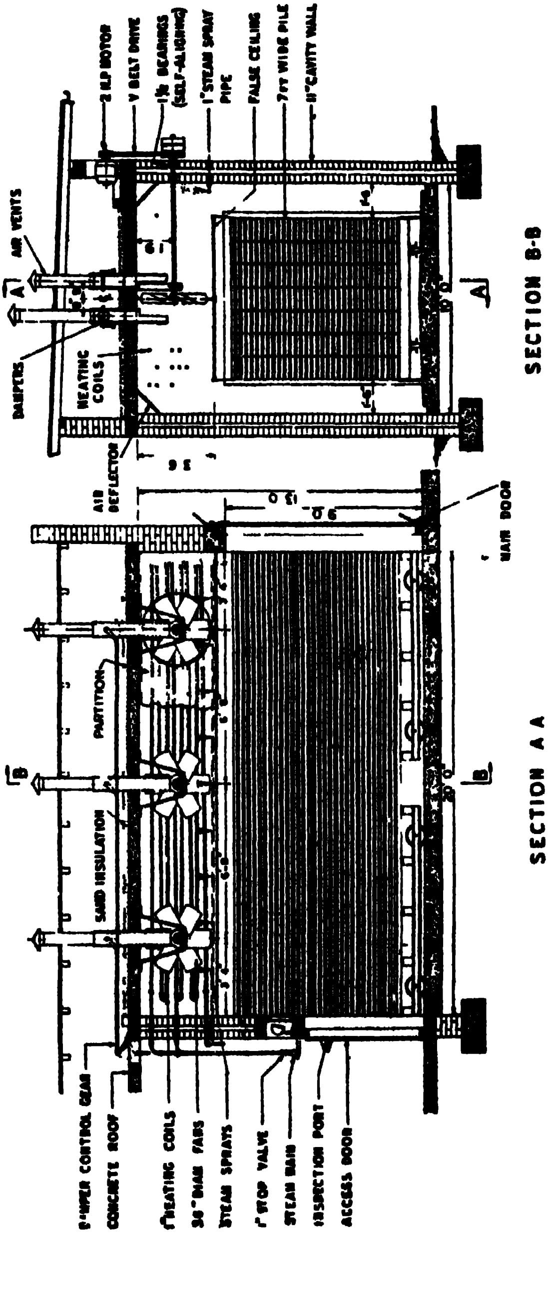


FIG. 36.—Longitudinal and sectional views of single-stack, cross shaft overhead fan kiln

By courtesy of the Director, F P R L, Princes Risborough.

secured with 3 feet diameter fans, reversible in operation, and driven at a speed of 500 r.p.m. by a 2 h.p. electric motor. Heating of the kiln is effected with 5 in. diameter wrought-iron flue pipes and headers. The flue gases from the sawdust-burning furnace enter the heating system through a manifold, situated half-way along the length of the kiln, travel to the headers at either end, and return through the pipes to an exhaust manifold.

Attention has been given to design of the furnace to ensure automatic feeding, steady burning, and constant heat output, and with a little experience on the part of the operator these ends are achieved. Unlike earlier patterns of furnace-heated kilns, reliance is not placed entirely on moisture expelled from the drying timber to maintain suitable humidity conditions; high humidities are provided by means of a system of water drips. Hence, humidity control is not effected solely by manipulation of the air inlet and outlet ducts. A distributor tank feeds water uniformly through pipes to convenient points along the length of the kiln, where it flows into horizontal troughs. Arrangements are made, by means of V-shaped pieces of copper wire, bound with cotton bandage, for drips of water to fall directly on to the top surface of the flue pipe below.

Separate consignments of 2-in. Douglas fir, 1-in. oak, and 3-in. Scots pine have been successfully dried in a kiln of this design; the Douglas fir from 50 to 17 per cent. moisture content in 9 days, the oak from 85 to 14 per cent. in 36 days, and the Scots pine from 17 to a 15 to 20 per cent. range in 15 days. In all cases it was not found possible to increase the humidity at the end of the run sufficiently to relieve the case-hardening stresses completely. In spite of this limitation, a furnace-heated kiln of this type obviously has considerable possibilities, and is a great advance on kilns similarly heated, but without provision for forced-air circulation or augmenting of the humidity by water drips. The kiln is fully described in *Wood*, September 1944.

Choice of kiln.—The primary conditions for determining the choice of the type of kiln to be installed depends on such points as first cost, the volume of timber to be handled, the space available for the kiln, the condition of the timber to be dried (*i.e.*, whether green or partially or fully air-dry), and the kind of

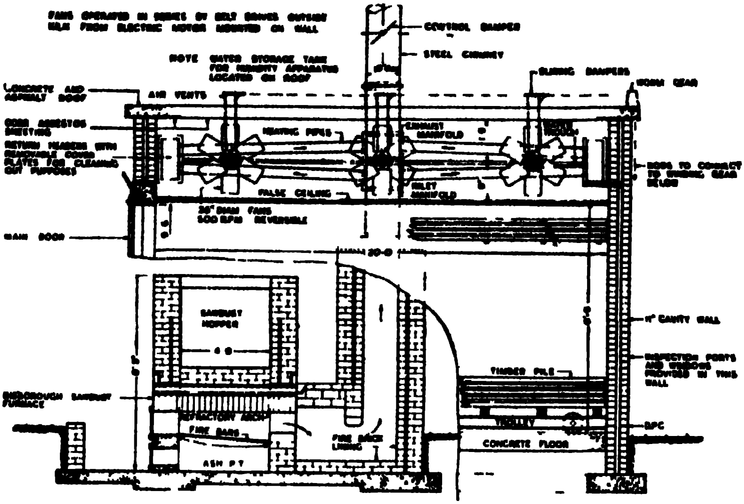


FIG. 37.—Longitudinal view of furnace heated kiln, and section through furnace

By courtesy of the Director, F P R L, Princes Risborough

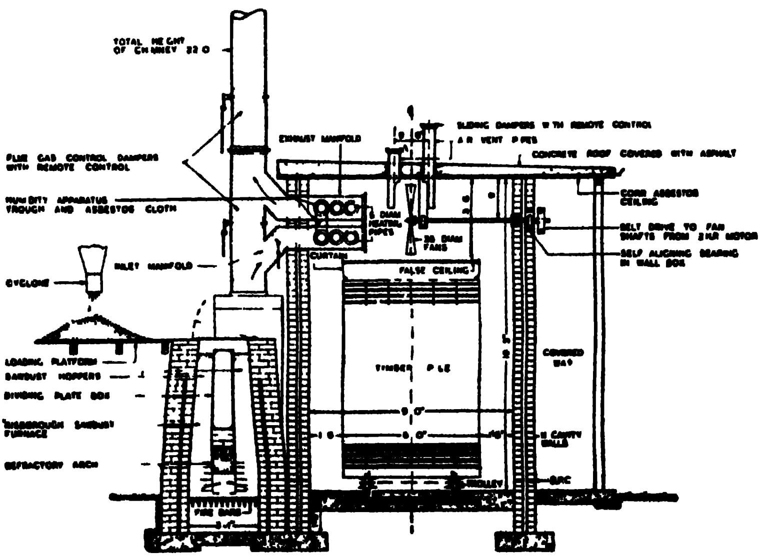


FIG. 38.—Sectional view of furnace-heated kiln

By courtesy of the Director, F.P.R.L., Princes Risborough

timber. The special merits of the different types of kiln have already been indicated.

Kiln installation involves considerable capital expenditure, so that first cost should not be allowed to weigh too heavily in the selection of a particular type of kiln: a higher initial cost may justify itself by proving more economical in the long run. For example, the more expensive forced-draught kiln provides a greater out-turn per cubic foot of kiln space than the natural-draught type, and it ensures the maximum control of drying conditions, thereby reducing degrade in seasoning to a minimum. Either of these factors may well justify the higher initial cost of installation of a forced-draught kiln. Of the two classes of forced-draught compartment kilns, the external-fan type is the more compact, and the operating apparatus is especially accessible, but the internal-fan kiln, particularly if of the overhead variety, provides more uniform drying conditions and fewer problems in securing proper air circulation. The last point is all-important; a kiln constructed in accordance with a standard set of plans will present problems of its own before air circulation under working conditions is correctly adjusted. The conclusions reached, as a result of extensive research, indicate that the overhead internal-fan kiln has much to recommend it, and, when starting from scratch, as opposed to modernizing an old-type kiln, it would seem inadvisable to ignore these findings. The double-stack and single-stack kilns described and illustrated above have been proved satisfactory in commercial operation; they are not unduly costly, and they are relatively simple both in construction and operation.

Kiln operation.—Successful kiln drying is very largely dependent on the skill of the kiln operator: a poorly designed kiln will give better results in the hands of a good man than the most up-to-date and efficient kiln in unskilled hands. It is essential to confine any run to one species and one dimension of stock; it is equally important to make proper use of kiln instruments, by siting them correctly and maintaining them in good condition; and progress of drying must be followed by means of sample boards. Given these essentials, it is also advisable to use a drying schedule that provides a margin for error: typical schedules for different timbers, published by the Government research laboratories, have been evolved from experimental

practice and provide such margins. Modifications may still be called for: good-quality material will tolerate more severe drying conditions than poor-quality timber; quarter-sawn boards will dry more slowly, but with less degrade, than flat-sawn material of the same species.

Examples of typical drying schedules are given in Tables V and VI. In both schedules it will be seen that the initial temperature is lower than the final temperature, and the initial relative humidity is higher than the final relative humidity. In effect, conditions in the kiln are made progressively more severe as drying proceeds.

Temperature and humidity control in the kiln is effected by manipulation of heating coil and spray valves, with occasional adjustments of air inlet and outlet dampers. Economy in operation of kilns is dependent on making the maximum use of the moisture extracted from the timber for maintaining the required humidity of the circulating air. This is effected by allowing only very slightly more moisture to escape *via* the outlet ducts than is being extracted from the timber, the deficit being made good by comparatively small amounts of steam from the steam spray system.

Warming up must not be too rapid because of the time lag in heating the wood to the recorded temperature of the air. Too rapid heating of the air in a kiln may result in condensation of moisture on the surface of the timber, which takes appreciably longer to warm up. Too high temperatures in the course of a kiln run are to be avoided, as high temperatures may darken the whole consignment. Rapid cooling at the conclusion of the run is frequently possible, but there is a risk that the hot timber will heat the cool air entering the kiln, making it appreciably drier, and this may lead to a renewal of case-hardening stresses or even splitting of the wood. It is suggested that a difference of 9° F. (5° C.) between wet and dry bulb readings should be maintained in the initial warming period, until the desired dry bulb reading is attained, and a similar difference during cooling, until the dry bulb reading has dropped to about 80° F.

The behaviour of different timbers in kiln drying varies enormously; in general, softwoods are much less refractory than hardwoods. With the latter, it is common practice to partially

TABLE V

LOW TEMPERATURE DRYING SCHEDULES, SUITABLE FOR TIMBERS THAT MUST NOT DARKEN IN DRYING AND FOR THOSE WITH A PRONOUNCED TENDENCY TO WARP [1]

Moisture content (%) of the wettest timber on the air inlet side at which changes are to be made	Temperature				Relative humidity % (approx.)
	Dry bulb		Wet bulb		
	°F	°C	°F	°C	
Green . . .	105	40	99	37	80
60 . . .	105	40	97	36	75
40 . . .	110	43.5	100	38	70
35 . . .	110	43.5	98	37	65
30 . . .	110	43.5	96	36	60
25 . . .	115	46	99	37	55
20 . . .	115	46	96	36	50
16 . . .	120	49	98	37	45
14 . . .	120	49	96	36	40

TABLE VI

DRYING SCHEDULE FOR TIMBERS THAT DRY VERY SLOWLY, BUT WHICH ARE NOT PARTICULARLY PRONE TO WARPING [2]

Moisture content (%) of the wettest timber on the air inlet side at which changes are to be made	Temperature				Relative humidity, % (approx.)
	Dry bulb		Wet bulb		
	°F	°C	°F	°C	
Green . . .	120	48.5	115	46	85
60 . . .	125	52	118	48	80
40 . . .	130	54.5	123	50.5	80
35 . . .	140	60	132	56	80
30 . . .	150	65.5	140	59.5	75
25 .	160	71	149	65	75
20 . .	170	76.5	156	68.5	70
16 . .	180	82.5	162	72.5	65
14 .	190	82.5	159	71	60

air-dry the stock first, as otherwise the kiln run is too long to be economical. Notwithstanding preliminary air seasoning, commercial kiln-drying schedules may occupy anything from a few days to three weeks or more.

CHEMICAL SEASONING

Air and kiln seasoning are methods of drying wood, aimed at making the material more suitable for use. **Chemical, or salt seasoning** as it is sometimes called, has exactly the same object.

Chemical seasoning rests on the principle that aqueous solutions of certain chemical substances have lower vapour pressures than pure water. By treating the outer layers of wood with certain salt solutions the vapour pressure of the contained moisture in these layers is reduced, which establishes a vapour-pressure gradient in the piece ; there is no immediate drying in the surface layers. Further, the equilibrium moisture contents of such chemically impregnated timber are higher than the equilibrium moisture contents of untreated wood, *vide* Fig. 39. In consequence, it is possible to maintain a vapour-pressure gradient, and therefore movement of moisture outwards in the piece, while the equilibrium moisture content of the surface layers is above fibre saturation point. The risk of setting up drying stresses in these layers is thereby eliminated. In theory, the careful adjustment of temperatures and humidities subsequently ensures continued, uniform drying to the final moisture content required, at a faster rate than is possible in safety with untreated wood.

Chemical seasoning involves treating the surface layers of green timber with a suitable chemical salt before the seasoning process is commenced.

Many chemicals and combinations of chemicals have been tried, and such different methods of application of the chemicals as dry-spreading, soaking, dipping, and spraying. The outstandingly cheap chemical for chemical seasoning is common salt (sodium chloride), which is, however, bad from the corrosive standpoint, and because of the liability of the treated timber to sweat subsequently. Urea has neither of these objections ; it has been employed on a considerable scale, both experimentally and commercially.

The depth of penetration of the chemicals in chemical seasoning

is usually not great: wet sapwood will take up the chemicals very quickly, but only the outer layers of the heartwood are affected. This is because absorption occurs by diffusion, which is rapid only if the moisture content of the wood is high enough to provide a continuous film of water within the wood into which the chemical can diffuse.

When drying treated timber, as in a kiln run, a moisture gradient is set up as in untreated wood, but with the all-important difference that the equilibrium moisture contents of the treated outer layers are different from those of untreated wood. Movement of moisture from the centre to the surface of the wood occurs while the equilibrium moisture content of the outer layers is well above fibre saturation point. This condition can be maintained for some time by constant adjustment of the relative humidity and temperature of the air in the kiln. By eliminating drying in the surface layers in the early stages, the whole consignment in a kiln can be dried in relative humidities that would cause untreated wood to check. Large-size timbers, 6 in. by 6 in. and up, of Douglas fir, for example, will surface-check when dried by relative humidities as high as 90 per cent., whereas the same timbers, after chemical treatment, have been safely dried with relative humidities of 75 per cent.

Chemical seasoning is most effective when the vapour pressure of the drying air is kept in equilibrium with the vapour pressure of the solution in the wood. This can be arranged, and yet allow the untreated interior to attain a moisture content in equilibrium with the drying conditions while the treated layers remain above fibre saturation point. It will be seen from Fig. 38 that the equilibrium moisture content of treated wood is at fibre saturation point until the relative vapour pressure of air at 70° F. falls below about 0·77, and for such atmospheric conditions the equilibrium moisture content of untreated wood is around 17 per cent. The curves for other temperatures are, of course, different, but they show a similar relationship. It will be apparent that, by selecting a suitable schedule for a kiln run, chemically treated wood theoretically can be dried almost to the final stage before the outer layers are dried below fibre saturation point, and seasoning stresses in the outer layers could, therefore, be eliminated.

Were wood to be dried so that the outer layers were still above fibre saturation point while the moisture content of the interior

fell to 17 per cent., stresses would result in the interior sufficient to cause honey-combing. This has actually occurred in experiments with salt seasoning. It follows that care must be exercised to ensure that, while eliminating drying stresses in the outer layers, stresses in the interior are also avoided.

Apart from the seasoning of large-size timbers, the practical outcome of chemical seasoning rests on this: can a suitable

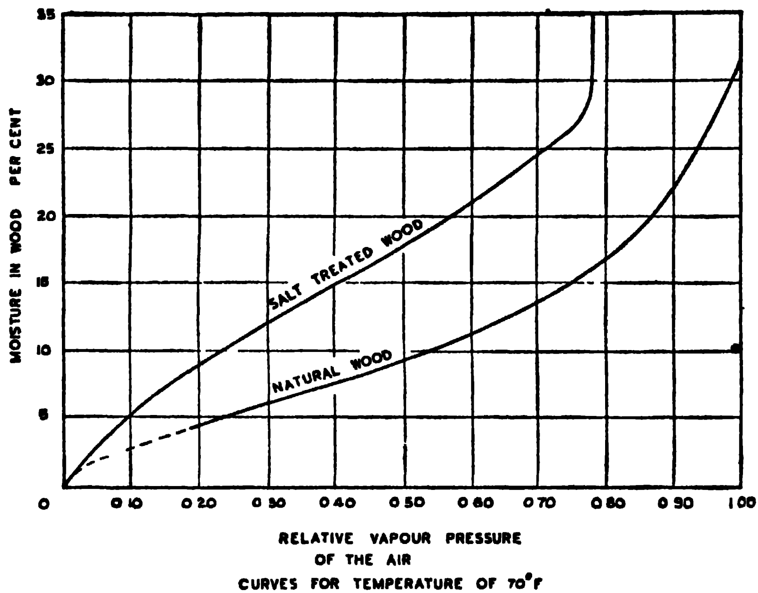


FIG. 39.—Equilibrium moisture contents for salt treated and natural wood for different relative vapour pressures (temperature of 70° F.)

By courtesy of the Director, F.P.L., Madison, U.S.A.

schedule be selected that is sufficiently fast to outweigh the costs of the chemical used and the double handling that the chemical treatment involves? Kiln-drying schedules that give perfectly satisfactory results have been worked out for untreated refractory timbers. Chemical seasoning must, in the circumstances, reduce the time of the run in terms of money, by at least as much as will be expended on the chemical treatment. for it to have any practical advantages. It is in this direction that the claims of chemical seasoning have yet to be proved. For example, with suitable drying schedules, urea is undoubtedly satisfactory, but with such

refractory timbers as English oak, it has not been possible to reduce the drying schedules sufficiently to justify its use on economic grounds. Complete success with English oak has only been achieved with schedules no more drastic than those suitable for untreated material of this species. The occasions when really large-size timbers are required fully seasoned must be comparatively rare, and the fact that they can be dried only with the aid of chemical treatments does not, in itself, bring chemical seasoning within the sphere of a practical seasoning method in ordinary circumstances.

There is another aspect to chemical seasoning than merely changing the moisture retention qualities of the surface layers of treated wood to permit of accelerating the drying process. This is the possible influence of the chemicals used on the hygroscopic properties of the cell wall structure. This aspect has been referred to as anti-shrinkage treatments. The theory is that during the process of treatment, and subsequent drying of the treated wood, some of the chemicals used may diffuse into the fine structure of the cell wall. As drying progresses moisture is given up, but the chemical absorbed is deposited in the walls and prevents their normal contraction. It will be apparent that appreciable quantities of a suitable chemical must be used to have a marked influence on total shrinkage — once more it is an economic question. At the same time, it is obviously desirable to assess both the moisture retention qualities and the anti-shrink properties of salts that may be used in chemical seasoning.

But cost, moisture retention, and anti-shrink are not the sole criteria. The chemical selected should be soluble in water, non-poisonous and harmless to handle, and with good storing qualities; it should not discolour the wood, nor affect such subsequent processes as painting, varnishing, and gluing. It must be non-corrosive to metals, as this would otherwise restrict the usefulness of the timber when dried, besides damaging the kiln in which the drying was done. Moreover, the dried, treated timber must not be (a) more recalcitrant to work with tools, (b) inclined to sweat when exposed to more humid conditions, (c) more inflammable, (d) more liable to insect or fungal attack, and (e) the electrical conductivity should not be increased. Some chemicals have fire-retardant and toxic properties, which enhance their usefulness.

In conclusion, it is not inappropriate to quote from an American

publication, *A primer on the chemical seasoning of Douglas fir*,[1] that appeared as far back as November 1938 : " In appraising the commercial significance of chemical seasoning a distinction must be made between what the process will do under ideal conditions and what it will profitably do under average commercial conditions. To say that timbers of a given size can be chemically seasoned without surface checking is quite different from saying that treated timber of the same size can safely or profitably be kiln dried in the average run of commercial kilns in a practical length of time. . . . In kiln-drying the more refractory items after chemical treatment, a hair-trigger control of drying conditions is required which is not often attained in commercial kilns." These truisms are no less applicable today, in spite of the knowledge and experience that has been accumulated in the intervening years. Chemical seasoning undoubtedly has wide possibilities, but it is not the panacea of every seasoning problem. Further, when comparing drying schedules for untreated timber with those recommended for chemical seasoning, it is imperative to know whether the same latitude has been allowed in both schedules. Drying schedules that have been published from time to time by Government research laboratories give the operator a margin for error. Such margins can by no means always be counted upon in schedules proposed by the enthusiasts for chemical seasoning.

DRYING OF WOOD ELECTRICALLY

The resistance of wood to the flow of electrical currents has been adapted for many years for measuring the moisture content of wood, *vide* pages 86 to 89. A development from this is the use of electricity for the drying and seasoning of timber. Initial experimental work, involving the use of low-frequency currents, has not given encouraging results: excessive splitting has been the common experience, suggesting the impracticability of this method for drying. It is not difficult to explain such excessive splitting : as wood dries it develops a very high resistance to the flow of an electric current, and consequently there is a considerable output of heat. This heat still further accelerates drying in

[1] Publication No. R 1278 of the Forest Products Laboratory, Madison, Wisconsin.

the immediate vicinity. In consequence, drying tends to be anything but uniform throughout the piece: the layers of wood immediately in contact with the plate or electrode dry out rapidly, while those further in are still wet. Such unequal drying sets up seasoning stresses, which are so pronounced that rupture of the tissues — or serious splitting — is inevitable. This, in point of fact, is the experience to date in the restricted amount of experimental work that has been done in the drying of wood by low-frequency electrical currents.

More recently, attention has been directed to the application of high-frequency alternating currents for drying purposes, and in plywood manufacture, for example, it may be said that high-frequency heating — also called radio-frequency heating or dielectric heating — has passed beyond the experimental stage and is a proven, practicable commercial method for the setting of glues. The application of the method to dimension timber, *i.e.*, boards, planks, and scantlings, has, however, been on a comparatively small scale, and under laboratory conditions. The results to date have, however, been highly encouraging: there seems to be no question that timber in ordinary commercial sizes could be so dried, both rapidly and with the minimum of degrade, but it cannot be regarded as economically practicable on a commercial scale for timber, except in veneer form, in the foreseeable future, because of the very high capital cost of the electrical apparatus required, and the cost of electricity, compared with steam, as a source of heat.

The theory behind the application of a high-frequency alternating current to the drying of wood is interesting, and it explains the freedom from seasoning degrade that the method secures. Certain substances are poor conductors of electricity, and when placed in the field of an alternating current of high frequency, they become hot. This is explained by the frequent re-alignment of the randomly arranged molecules of the poor-conducting substance, induced by the constant change in direction of flow of the electrical current: such changes in position, rapidly repeated, cause the generation of heat. Expressed diagrammatically, we may assume that the complex molecules of wood substance are arranged as in Fig. 40 (*A*). The molecules are then placed in the field of an alternating current of high frequency by means of two plates, or electrodes, placed on either side of the piece of

timber, and connected up in a high-frequency field. When the current is switched on the molecules proceed to rearrange themselves, taking up positions as in Fig. 40 (*B*). Alternation of the current, that is, reversal in direction of the flow, results in realignment of the molecules as in Fig. 40 (*C*). The constant change in

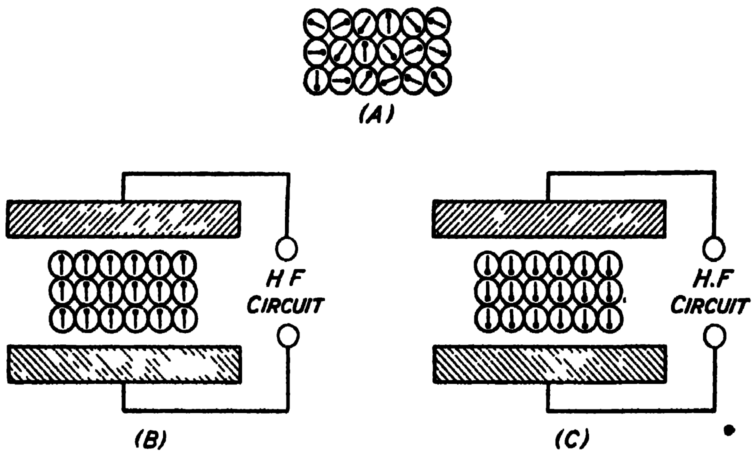


FIG. 40.—Diagrammatic representation of realignment of molecules placed in a high-frequency field. (Drawn by T. W Paddon, Esq.)

By courtesy of the Cleaver-Hume Press

direction of the flow of the electrical current, causing constant change in position of the molecules, results in the generation of heat. This heat in turn induces water movements in the wood: in fact, drying or seasoning proceeds. The great advantage of this method of drying is that from the commencement, all the molecules making up the wood substance of the piece, enclosed in the high-frequency field, are involved: heat is generated equally in the centre and in the outside layers of the wood. In consequence, moisture movements set up are not confined to the outer layers, as with low-frequency currents, and drying of the wood proceeds uniformly throughout. It follows that this reduces seasoning stresses to a minimum, and, consequently, degrade is eliminated.

CHAPTER XI

DEFECTS IN TIMBER

Timber, being a natural product, is seldom entirely free from blemishes and other imperfections that tend to lower its economic value ; these are spoken of collectively as **defects**. A feature that in some circumstances is considered a blemish may, in different circumstances, be held to enhance the appearance of a piece of wood, when it would not of course be classified as a defect.

Defects may be classified under two broad heads : natural defects, that is, defects resulting from factors influencing the growing tissue of the living tree, and defects resulting from the activity of external agents or the subsequent treatment of felled timber. Defects caused by fungi and insects are discussed in separate chapters (Chapters XII and XIII).

NATURAL DEFECTS

Knots are, perhaps, the commonest type of defect in timber. As the tree increases in diameter it gradually envelops the bases of the branches ; the portions of the branches enclosed within the wood of the trunk are called knots. If the branches are alive at the time of their inclusion their tissues are continuous with those of the main stem and the knots so formed are said to be **live** or **tight knots**. When a branch dies a stump remains which is gradually surrounded by the tissues of the trunk, but, being dead, its tissues are not connected with enveloping tissues of the main stem, and a **loose** or **dead knot** results ; such knots fall out either when timber is converted, or after it is seasoned and when it is being worked up. The broken stubs of dead knots provide ready access to decay and, consequently, dead knots are frequently unsound.

Knots vary in size from little more than a pin-head to several inches in diameter They also vary in shape, according to the angle at which they are cut through during conversion. A **round knot**, for example, is more or less circular in form, as seen on

the face of a board, and a **spike knot** is one sawn through in a lengthwise direction. Knots have an important bearing on the utilization of timber; in many species they are the primary cause of degrade, *i.e.*, a lowering of quality below the best or prime quality for the particular type of timber. Knots may spoil the appearance of boards, although in "knotty pine" the abundance of knots is regarded as a decorative feature, and such timber is popular for panelling in America. Irregularity of the grain in the region of knots reduces strength properties, besides giving rise to seasoning defects and difficulties in wood-working. The effect of knots on the strength properties of wood is discussed on pages 136 and 137.

Bark pockets.—Pockets of bark are sometimes included in the wood of the main stem. They result from injury to the cambium. Growth ceases locally until the adjacent cambium has completed the occlusion of the damaged area, resulting in portions of bark becoming embedded in the wood. Such pockets obviously constitute a defect, the seriousness of which depends on the size of the pocket and the extent to which decay may have developed in the vicinity. A bark pocket in a plank of chengal is illustrated in Plate 49, fig. 2; this pocket undoubtedly originated from an old tapping cut.

Pith flecks.—Patches of abnormal parenchymatous tissue, called **pith flecks**, occur in some timbers, as a result of the tunnelling of the cambium by the larvae of certain insects. Pith flecks are usually wider tangentially than radially, and extend considerable distances vertically; their inner faces follow the outline of the cambial sheath and their outer faces are irregular in outline (Plate 48). Pith flecks are a common feature of some timbers, *e.g.*, alder, birch, maple, sycamore, but they are not sufficiently constant in occurrence to be of more than subsidiary value in identification.

Included phloem, although a normal feature of some timbers, is usually considered a defect as far as utilization is concerned. (See page 45 and Plates 25 and 23, fig. 4.)

Pitch pockets are described on page 28, and illustrated in Fig. 7. In the Canadian literature they are classified according to size as *small*, *medium*, or *large*. When a pitch pocket is cut through at its widest part, so as to appear as a shallow opening on the longitudinal face of a piece of timber, it is called a **pitch**

PLATE 48

Pith flecks in birch. The upper portion of the figure shows the appearance of pith flecks on cross section and the lower portion their appearance on a longitudinal face.

Photo by F. P. R. L. Princes Risborough

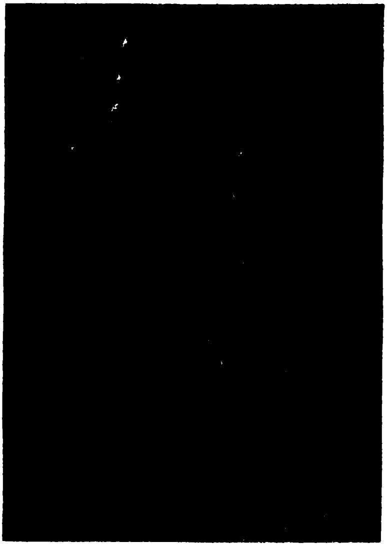


FIG. 1 A resin pocket in a plank of balau

Photo by F. R. I. Kepong Malaya

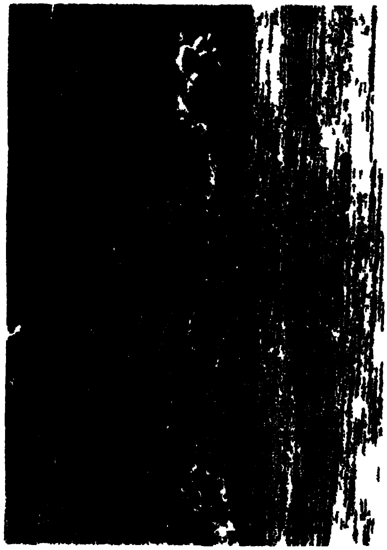


FIG. 2 A bark pocket in a plank of chengal

Photo by Timber Research Laboratory Sentul Malaya

FIG. 3.—Typical compression failure in [illegible] seasoned board; such failures [illegible] timber dries and [illegible] ous

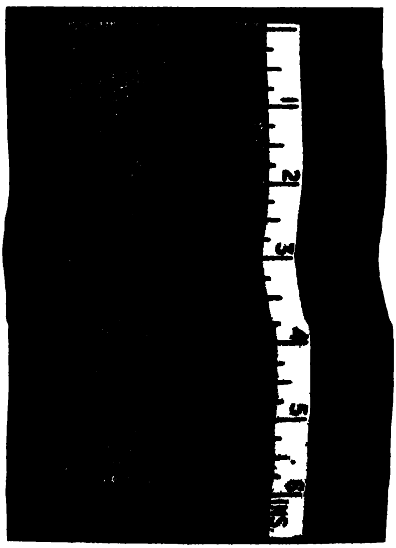


FIG. 4 Strawberry mark in Sitka spruce appearance on quarter sawn surface

Photos for Figs 3 and 4 by F. P. R. L. Princes Risborough

blister. Pitch seams or shakes are openings along the grain that follow the outline of the growth rings. Pitch pockets, blisters, seams, or shakes are for the most part defects of softwood species, but similar defects also occur in one hardwood family, the *Dipterocarpaceae*. In this family, however, defects of the types referred to are much smaller than typical, corresponding defects in softwoods, and their contents are usually solidified dammars or oleoresins. A resin pocket in a plank of balau is illustrated in Plate 49, fig. 1.

Gum veins are traumatic canals that occur in some woods (Plate 22, fig. 4); they are usually filled with dark-coloured deposits. In some timbers, *e.g.*, jarrah, they are usually infrequent in occurrence, but timber from fire-swept forest may contain gum veins in considerable numbers that constitute definite defects; in other timbers, *e.g.*, African walnut, they are so frequently present as to constitute a characteristic feature of the wood, which may, however, enhance its appearance.

Mineral streaks are defined as "localised discoloration of timber, in the form of streaks or patches usually darker than the natural colour, which does not impair the strength of the piece".[1] Mineral streaks have been found in sycamore and wych-elm. The term has also been applied to the light-coloured streaks occurring in timbers of the family *Dipterocarpaceae*, *e.g.*, lauan, meranti, seraya, keruing, gurjun. These streaks are really the resin canals in longitudinal section, which, because of their white or yellow contents, show up against the red or brown background of the wood.

Resin streaks or **pitch streaks** are narrow brown streaks extending along the grain, and fading out gradually, that occur in spruce, Douglas fir, and other softwoods (Plate 54, fig. 4). They are caused by local accumulations of resin in the tracheids. Resin streaks may sometimes be confused with discoloration caused by incipient decay, but can be distinguished because the darkened wood is not soft or otherwise affected; the strength properties are not influenced in any way.

Strawberry mark is a minor defect sometimes encountered in Sitka spruce. The discoloration is caused by accumulation of resin, and consists of a red-brown zone up to 1 in. wide and

1¼ in. high, running radially through the wood. In truly radial faces the defect appears as a bar of darker-coloured wood running across the piece, but, if the cut surface is oblique, the discoloration usually appears more as in Plate 49, fig. 4. Unless the accumulation of resin is accompanied by enlargement of the rays to many times their normal size, the strength properties of the wood are unaffected, and the defect is no more than a minor blemish.

Latex canals are described on page 45, and illustrated in Plate 24. The large canals occur in relatively few woods, *e.g.*, those of the family *Apocynaceae*; in grading they cannot be treated as ordinary defects as they are a natural feature of the structure of such timbers. For some purposes, *e.g.*, as cores for veneer surfaces, and uses requiring timber in short lengths, the presence of latex canals is immaterial.

Compression failures are zigzag hair cracks that occur across the grain near the centres of some logs, *e.g.*, African mahogany, lauan, meranti (Plate 49, fig. 3 and Fig. 41, *g*). It is thought that these fractures arise as a result of wind action or other external forces bending the trunk of the tree during the early years of its life. Compression failures often become visible only as drying proceeds, appearing as very fine checks or splits. These checks may be present in green timber, or the fractures in individual cell walls may join up with those in adjacent walls, to form continuous ruptures in the tissues, as a result of the stresses set up in drying. Compression failures are often associated with the presence of " spongy heart " or " punky heart ". Compression failures are a serious defect if present in large numbers, rendering timber valueless for most purposes. Their influence on strength properties are discussed on page 136. Affected boards will often break in two when lifted, a condition that has given rise to the expressive term " *three-men-boards* ", the third man being required to support the timber in the middle! Other names for compression failures are *thunder-shakes*, *lightning-shakes*, and *cross-breaks*. The presence of compression failures should be suspected when the saw leaves a clean surface of horizontally-broken fibres, as seen on longitudinal surfaces, instead of the more usual, uneven, long fibrous surface.

DEFECTS ARISING FROM OTHER THAN NATURAL CAUSES

SEASONING DEFECTS

Next to knots the commonest causes of degrade in timber are defects resulting from faulty seasoning technique. It has been explained that as wood dries it shrinks, and that the shrinkage is not uniform in all directions. Moreover, the outer layers of a piece of wood tend to dry out more rapidly than the interior, resulting in temporary or permanent distortion of the timber, and even in the separation or rupture of the tissues. The different forms of permanent distortion of timber and of ruptures of tissues are defects; separately and together they are referred to as **degrade in seasoning** or **seasoning degrade.** Permanent distortion gives rise to various forms of **warping,** and ruptures of tissues to **checks, splits,** and **shakes.**

Cupping is a warping across the width of a board (Fig. 41, *b*). In flat-sawn material one surface is more nearly radial than the other, and, since radial shrinkage is less than tangential, the side towards the pith tends to shrink less than the opposite face; if this side of a board does shrink less than the opposite face, the board will be distorted or warped when dry; it becomes bowed or cupped in cross section. Cupping can be reduced by proper piling, *vide* last sentence of next paragraph. The defect does not occur in truly quarter-sawn material.

Twisting is the spiral or corkscrew twisting of a board or plank in a longitudinal direction as it dries, which, in extreme cases, may render the timber valueless (Fig. 41, *a*). Twisting can usually be traced to spiral or interlocked grain, although it may also result from unequal shrinkage brought about by variation in density within the board or plank; it can usually be minimized, if not completely eliminated, by weighting stacks with heavy baulks immediately the pile is built and before drying has commenced.

Bowing is a warping (or sagging) from end to end of a piece of timber (Fig. 41. *d*); that is, it is similar to cupping except that it occurs along the length of the piece and not across its width. Bowing results from too wide spacing of stickers, which causes the timber to sag under its own weight.

Spring is distortion in the longitudinal plane, the board or plank remaining flat (Fig 41, *i*). Spring is not uncommon in boards from near the "core" or "heart" of a log, and is the result of the sudden release of internal stresses when the log is sawn

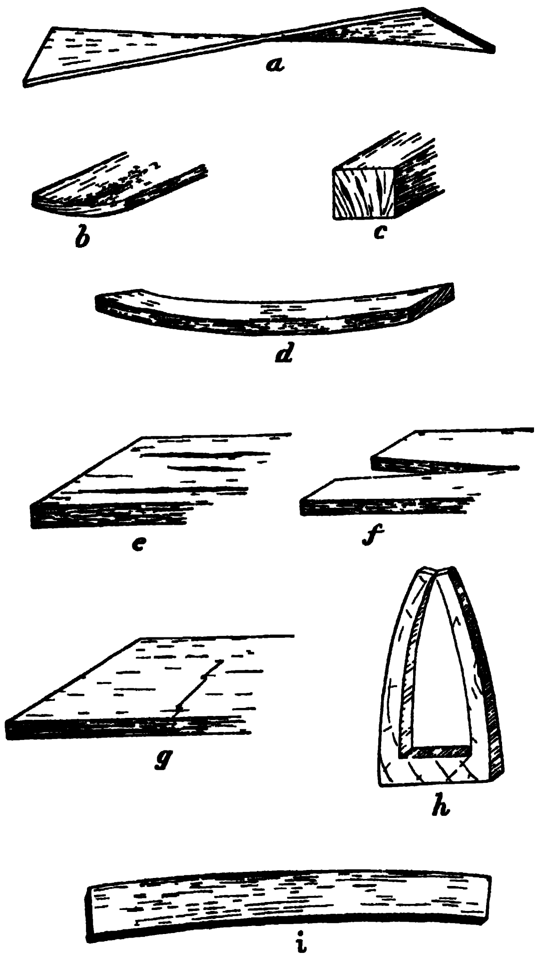


FIG 41—*a*, twist, *b*, cupping, *c*, honey comb checks, *d*, bowing, *e*, checks, *f*, end split, *g*, compression failure, *h*, behaviour of test sample from a case hardened board, *i*, spring

through. All timber is more or less subject to spring, but that of certain species is more susceptible than others. In extreme cases, spring can be so serious as to make conversion uneconomic: some kempas from swamp areas springs to such an extent that

distortion of both ends of a scantling is measurable in feet rather than in inches.

Checks and *splits* are separations or ruptures of the wood tissues in the longitudinal plane and are distinct from the horizontal fractures, " thunder-shakes " or compression failures, that have their cause in other factors than drying stresses. A check is a separation of the fibres that does not extend through the timber from one face to another (Fig. 41, *e*), and splits are separations extending from face to face. An end split is one that occurs at the end of a log or piece of timber (Fig. 41, *f*).

Checks and splits may close up if the dry timber is subsequently exposed to damp conditions, but once the fibres have separated they cannot actually join together again, and the checks and splits are present although they may not be visible.

Shakes.—Serious splits are often called " shakes ", but it is better to confine the use of this term to separations of the fibres in timber of large size or in the log; shakes may originate from other causes than drying stresses, *e.g.*, from careless felling, internal stresses existing in the living tree that are released when the tree is felled. Shakes are of several types, *e.g.*, **ring-shake**, where the separation follows a growth ring, **star-shake** where the ruptures radiate outwards from the pith.

Case-hardening.—When timber is dried so rapidly that the outer layers want to shrink while the interior is still saturated a stress is set up, because the outer layers are restrained from shrinking normally; they may eventually shrink the full amount, when checks will result, or they may set in a distended or stretched condition (**tension set**); pieces of timber in which this latter condition occurs are said to be **case-hardened**. Case-hardening can be removed by steaming, to restore moisture to the outer layers. If steaming is applied in time, and subsequent re-drying is properly controlled, previously case-hardened timber that has not surface-checked or become honey-combed is in no way inferior to timber that has never been case-hardened. Case-hardened timber may cup and develop other forms of distortion when it is subsequently re-sawn or worked up (see also discussion on pages 93 and 94, and Fig. 30).

Honey-combing.—If case hardening is not relieved by steaming, the outer layers set without shrinking the normal amount, and when the interior dries below the fibre saturation point it,

too, is restrained from shrinking, and interior checks may result. This condition is known as **honey-combing**. The stresses set up are greatest tangentially, because shrinkage is greatest in this direction, and the resulting separation of the fibres is always initiated where the tissues are weakest: that is, along the rays (Fig. 41, *c*).

Checks caused by conditions leading to case-hardening may close, and honey-combing checks may not extend to the surface, so that the defects cannot always be detected before the timber is worked up. A simple test for case-hardening is described on page 176, and illustrated in Figs. 31 and 41, *h*. Honey-combing can be detected by cutting a plank through about 1 foot from the end and noting whether there are any internal checks along the rays on the freshly exposed end.

COLLAPSE

Some timbers are liable to a defect known as **collapse** if kiln-dried slowly at too high humidities, or at too high temperatures. The use of high humidities while timber is high in moisture content, and the type of timber, may also appreciably affect the amount of collapse occurring. Collapse can also occur in rapid air-drying of very green timber of a few species, *e.g.*, Tasmanian oak, western red cedar, cypress, and hemlock: the cells are flattened in drying, which is manifest in the more porous early wood, producing, in extreme cases, a corrugated surface — hence **washboarding** — of quarter-sawn faces (Plate 50). Collapse results in excessive and often irregular shrinkage, and may lead to appreciable distortion, *vide* Plates 51 and 52; in some extreme cases severe internal checking may occur. The defect is serious because, in addition to the loss of timber in trimming mis-shapen pieces of wood, and the abnormally high shrinkage already referred to, the strength properties of the wood may also be reduced. Collapsed air-dry wood is, however, usually stronger than non-collapsed or reconditioned wood, primarily because it is more dense.

No uniform behaviour can be assigned to the effect of position in the tree in relation to the occurrence of collapse. As regards the locality factor, Australian experience suggests that timber from moist or swampy places, and fast-grown, immature trees, is more prone to collapse than material from other sources.

PLATE 50

"Collapse" producing "wash boarding" in a board of Tasmanian oak

Photo by Division of Forest Products, C.S.I.R., Australia, by courtesy of Dr H. E. Dadswell

PLATE 51

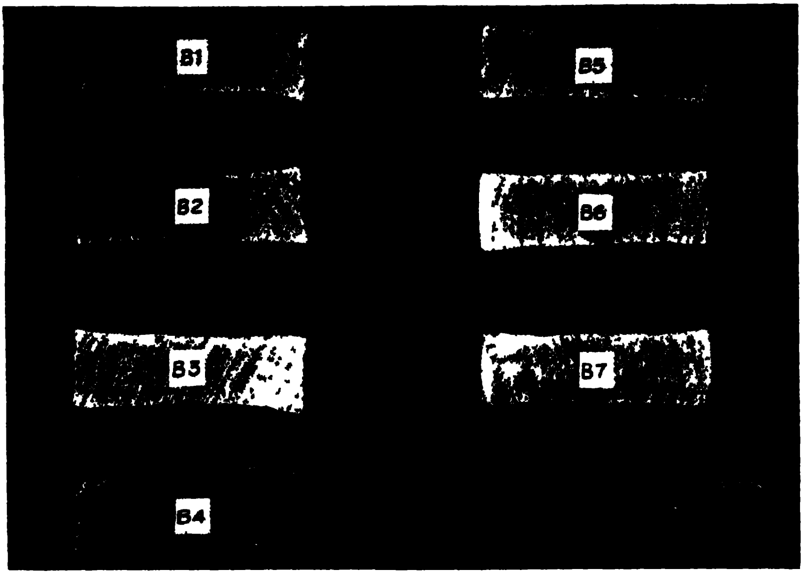


FIG. 1 Before treatment

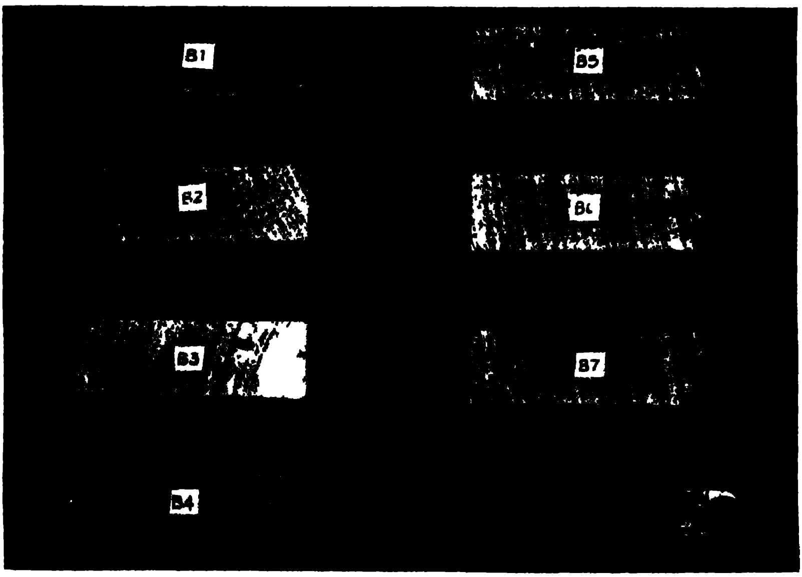


FIG. 2. After treatment

Re-conditioning of collapsed Tasmanian oak

Photos by F. P. R. L. Princes Risborough

The cause of collapse has given rise to divergent theories. There are indications that some collapse may ordinarily occur in the drying of any timber, but this is not what is normally meant by the term. Until recently it was supposed that pronounced collapse required the cells to be completely filled with water, and the cell walls to be almost completely impervious. Collapse was then explained by the effect of internal tensile forces set up during drying in the water occupying the whole of the cell cavities of affected cells. This theory called for no bubbles in the cell cavity water larger than a certain minute minimum, and supposed that if water were lost by diffusion through the cell walls faster than air or water vapour entering the cells, a state of tension would arise in the water remaining in the cell cavity. The forces of cohesion between the water molecules and faces of contact between the water and the cell walls would result in a state of tension of the water sufficient to contract and draw in the cell walls. A recent mathematical analysis by W. H. Banks and W. W. Barkas attributes collapse to surface tension phenomena, and explains the occurrence of collapse when some air is present. Collapse is naturally more severe with kiln drying, because the temperatures used increase the rate of drying and also the plasticity of the cell walls.

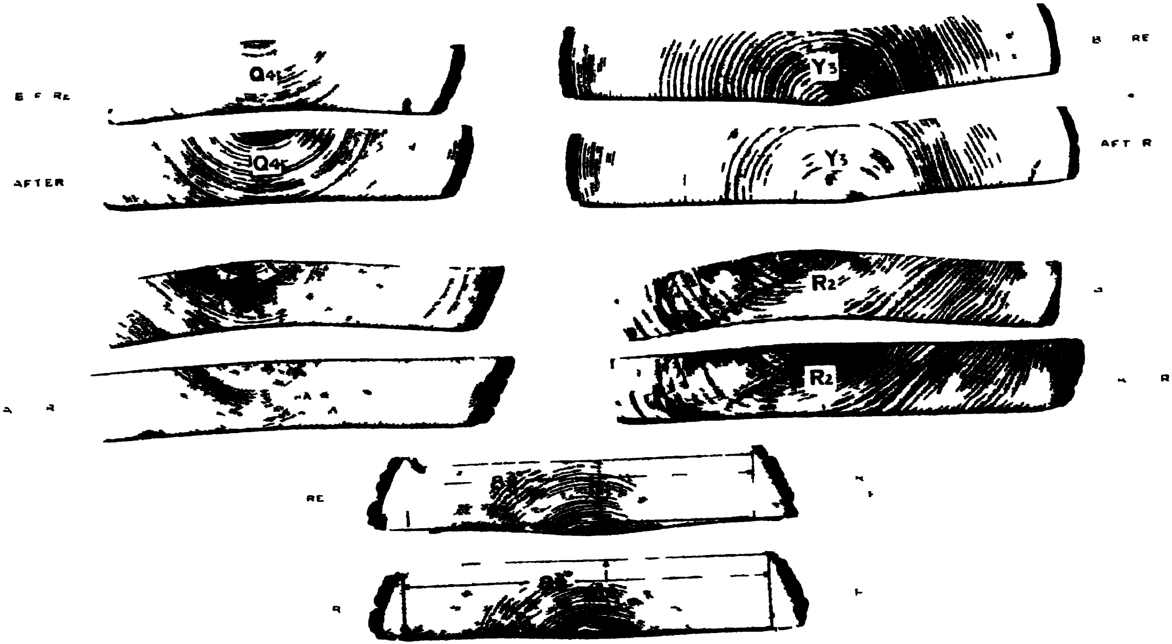
A method of re-conditioning has been evolved for removing collapse with complete success. It consists in heating collapsed timber in a chamber in saturated air to a temperature of about 210° F., and maintaining these conditions for some hours before allowing the timber to cool. Plate 51, fig. 2 shows the effect of re-conditioning the timber illustrated in Plate 51, fig. 1, for a period of four hours; the final moisture content was increased only by ½ per cent., and there was an appreciable gain in cross-sectional area. Slight checking of no commercial importance occurred on the edges; the strength properties of the re-conditioned timber were not lowered in comparison with uncollapsed material of the same moisture content. Machining qualities and working properties generally were improved. Equally successful results have been obtained with other species.

Timber that is badly warped or cupped, without apparently being collapsed, may also be successfully re-conditioned: distortion may be sufficiently removed to secure a marked increase in the final cross-sectional area. Even apparently "normal"

shrinkage has been reduced by a re-conditioning process, *vide* Plate 51. This consignment had cupped slightly, but suffered little distortion, and re-conditioning effected an increase of 23 per cent. in available cross-sectional area over the original kiln-dry dimensions. Australian work suggests that when reduction in "normal" shrinkage is achieved, it is because unsuspected collapse has been removed.

Re-conditioning, then, besides removing collapse, may be employed to remove distortion resulting from other causes, and it is also effective in reducing normal shrinkage. It is not suggested that re-conditioning should be a complement to kiln seasoning in every case, but the results obtained have been so striking that its possibilities are not without practical significance; they deserve to be more fully investigated on a commercial scale.

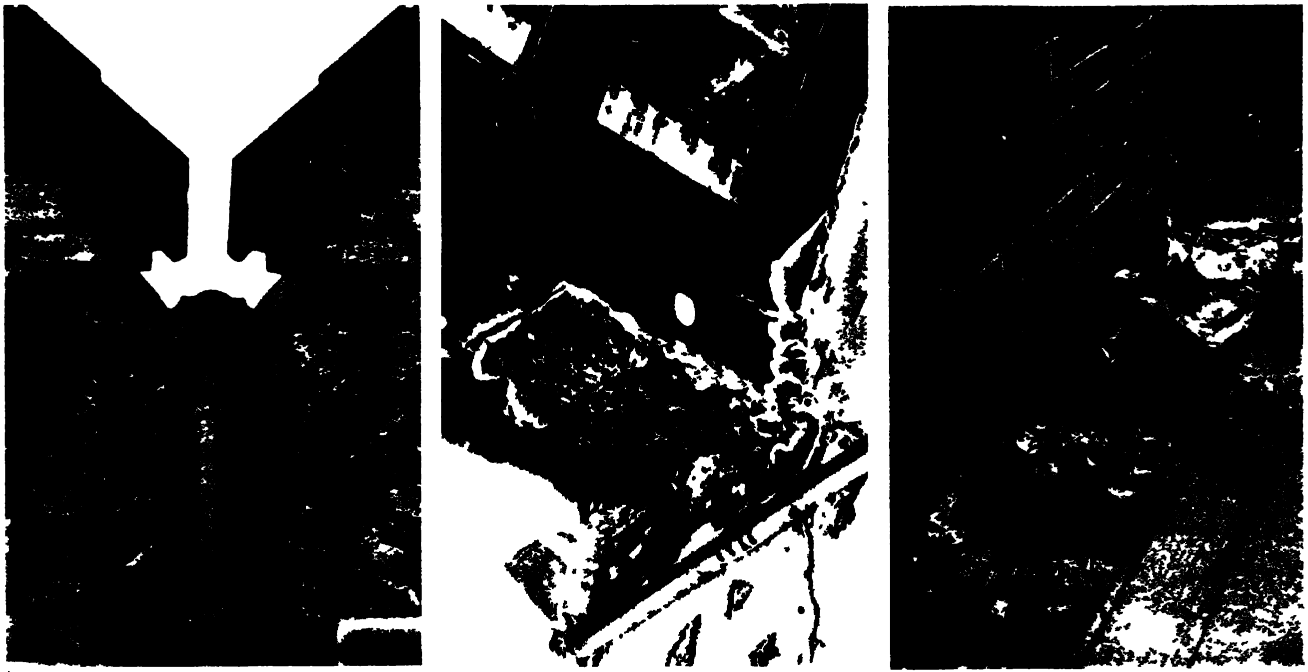
PLATE [illegible]2



Cross sections of ash planks before and after reconditioning

Photo by F P R L Princes Risborough

PLATE 53



(a) (b)

Neglect of maintenance as a cause of decay in wood. (a) Stopping up of rain water head and a leak in the lead lined gutter behind produced conditions leading to (b) vigorous growth of *Merulius* in the gutter bearer and (c) serious decay of the floor joists immediately below.

CHAPTER XII

DECAY AND SAP-STAIN FUNGI

GENERAL PRINCIPLES

Most forms of decay and sap-stain in timber are caused by certain plants, called **fungi**, that feed either on the cell tissue or cell contents of woody plants. It is important to distinguish between **wood-rotting fungi**, responsible for *decay* in timber, and those that feed on the cell contents, causing *stains*. The former consume certain constituents of the cell wall, and lead to the disintegration of woody tissue, whereas the latter remove only certain stored plant food material in the cell cavities, leaving the cellular structure intact. Wood-rotting fungi seriously weaken timber, ultimately rendering it valueless, whereas **sap-stain fungi** spoil the appearance of wood, but do not affect most strength properties. Sap-stain is, in effect, not a preliminary stage of decay, but such stained timber, exposed to suitable conditions, may later be attacked by wood-rotting fungi.

Wood-rotting and sap-stain fungi belong to a large group of plants that includes edible mushrooms and toadstools. The visible mushroom or toadstool is the **fruit body** or **fructification** of the fungus, the vegetative parts of the plant being out of sight, in the feeding medium. The fruit bodies of wood-rotting fungi are frequently flat, fleshy or woody, plates, the undersides of which bear **spores** or seeds. The destructive part of a fungus is its vegetative system, or **mycelium**, made up of numerous exceedingly fine tubes called **hyphae**; these may become matted together to form a felt-like mass. Hyphae grow by elongating at their tips, passing from cell to cell of the host plant, feeding on the walls or cell contents in their path. The complete life cycle of a fungus is, therefore, (1) spore, (2) hyphae, (3) mycelium, (4) fruit body or fructification, and (5) spore.

All fungi feed on organic material of either plant or animal origin. Those of interest to the user of timber attack *either* living (probably unhealthy) trees, *or* felled timber. One condition essential to the development of all fungi is the presence of sufficient moisture: initial infestation will not occur in any timber below 20 per cent. moisture content. Moreover, reduction of moisture below the critical minimum causes all fungi to cease growing. Some fungi are, however, capable of extending their attack to adjacent timber near the critical moisture contents, when growing vigorously; they will not ordinarily initiate attack unless the moisture content is about the fibre saturation point, and many fungi require appreciably higher moisture contents to initiate attack. Some fungi transport moisture from an outside source, or produce their water requirements from the break-down of cell-wall substance in their path, enabling them to raise the moisture content of wood just below the 20 per cent. level to this level. Reduction in moisture content is not sufficient to bring about the immediate death of a fungus: hyphae are capable of remaining in a dormant condition for several months, but even those of the "dry rot" fungus will not survive for a year in normally dry conditions.

The conditions essential to fungal growth are four in number:

(1) Food supplies	(2) Adequate moisture
(3) Suitable temperature	(4) Air (oxygen) supplies

In most circumstances growth of fungi in wood under service conditions is dependent solely on the presence of adequate moisture. The wood itself, or the cell contents of the sapwood of certain species, constitutes the necessary food supply, and oxygen can always be obtained, except in a vacuum or gas-tight chamber, or under completely water-logged conditions. Some timbers, however, contain extractives of an oily or solid nature that are poisonous to fungi; these substances render the wood unsuitable as food, thus explaining why some timbers are "naturally durable". That is, they are resistant to attack, but not immune. Practically all fungal growth ceases at or below freezing point (32° F.), and is very slow at temperatures below 40° F. Hence, in temperate regions with really cold winters, fungi may be quiescent in the winter months, and temperatures are a limiting factor in polar regions; optimum temperature conditions vary with different fungi, but are in the region of 65° to

85° F. In apparent contradiction to the foregoing, the wood-work of cold-store rooms and refrigerators is not infrequently attacked by fungi: this is because the wood is not at the temperature of the artificially cooled space, being part of the surrounding insulation and, therefore, at some higher temperature, often not much lower than that of the outside atmosphere; further, such timber is liable to become damp as a result of condensation from warm air striking the cooler timber of the cold store.

The presence of decay is often visible from the spongy appearance of the ends of logs, compared with the more fibrous end surfaces of sound logs. Actual decay is the final stage of attack; by this time the colour and texture of the infected wood have been changed, and most strength properties have been appreciably reduced. Beyond the decayed area, and in the early stages of infection, a state of incipient decay exists: no visible changes in structure may be apparent, and only slight colour changes or softening may occur; strength properties are likely to be only very slightly reduced. Sterilization at this stage will arrest decay, when, provided attack was very slight, such timber is likely to be as good as sound stock, and it will be perfectly safe after sterilization, as far as the risk of spreading infection is concerned. On the other hand, in carrying out repairs necessitated by fungal activity, it is not sufficient merely to cut out all visible signs of "decay", a margin of safety should be secured by cutting well back beyond the last traces of any incipient decay. In addition, adjacent surfaces, whether of brickwork, masonry, concrete, or metal, should be heat-sterilized, so long as the fire-hazard permits, or the surfaces should be treated with a fungicide. The limitations of heat-sterilization are discussed later, *vide* page 270; the special precautions to be observed in selection of timber for repairs is discussed on pages 51 to 53.

Wood-rotting fungi are of several kinds. Those that attack living trees produce the familiar "brown rots", "pocket rots", and some forms of "spongy heart", and hollow cores, in old trees. Decay of this type may be detected by the abnormal colour of the timber, by the transverse fractures of the fibres on longitudinal sawn faces, and by lifting the fibres with the point of a penknife, when, if the timber is decayed, the fibres will snap, instead of pulling out in long splinters. The important distinction between the wood-rotting fungi, and other fungi, is that the former live

on certain constituents of the woody cells of plants.

It has already been stated that the two main constituents of wood substance are cellulose and lignin. The **brown rots** feed mainly on the cellulose, and the **white rots** feed both on cellulose and lignin, but to a varying extent, depending on the particular fungus. The different wood-rotting fungi can be further subdivided, according to the form decay takes, into cubical, spongy, pocketed, stringy rots, and so on. The terms **dry rot** and **wet rot** are misleading: 20 per cent. moisture content is a critical minimum moisture content for active growth of all fungi. Most fungi require the moisture content of wood to be between 35 and 50 per cent. for optimum growth, and some appear to prefer still wetter conditions. Precise figures for different fungi are virtually impossible to arrive at; it is known, however, that the minimum moisture content required for spores to germinate is higher than the figure for infection of wood adjacent to actively growing mycelium, or for fungi already present to continue growing. In the final stages of decay, caused by those fungi that continue active in wood near the critical moisture content, the wood may be dry and friable, and this has led to the use of the term "dry rot", whereas, in the final stages of decay caused by fungi that require wood to be comparatively wet for them to initiate or continue attack, the affected area is often itself wet, hence the term "wet rot". The term "wet rot", however, is sometimes mistakenly applied to the slow disintegration of wood exposed to the weather, *i.e.*, **weathering**, which may be quite independent of fungal activity. Constant exposure results in a softening of the surface of wood, and repeated wetting by rain, followed by rapid drying in the sun, leads to the development of numerous surface checks that split the surface layers into small cubes or rectangles. Once disintegration has commenced, conditions are, of course, favourable for fungal infection.

Apart from the confused use of the term "wet rot", the attempted distinction from "dry rot" is unsound; fungal attack is dependent on damp conditions. Equally, "dry rot" is an unsatisfactory term: in the tropics it is often applied to damage caused by dry-wood termites, *vide* page 234.

Pocket rots take the form of apparently localized areas of infection, scattered over the surface of a board or plank; areas are frequently discoloured, or they may be white; they are easily

dented with a thumb-nail or the point of a penknife. In the timber trade this type of infection is frequently referred to as dote.

Many fungi are essentially forest problems: there are fungi that attack logs that have been lying in the forest until thoroughly saturated, and there are others that attack standing but unhealthy or over-mature trees, or freshly felled logs. Fungi that attack timber in service may belong to neither of these classes; they are relatively of much greater economic importance, but they can be kept within bounds provided simple precautions are observed.

Forest fungi.—Fungi that attack old logs are unimportant, since such logs would never be converted for timber. Fungi that attack standing trees, or freshly felled logs, on the other hand, are responsible for losses, principally to owners of forest; they need not be a problem to the consumer of wood. These fungi belong to the class that attack decidedly wet wood, which, once seasoned, is, however, safe from development of further decay. Moreover, for indoor purposes, such seasoned wood is unlikely to encounter conditions that would lead to renewal of attack by "forest" fungi that require relatively high moisture contents for their active growth. During conversion of timber known or suspected of having been attacked by "forest" fungi, all wood containing visible areas of infection should, and probably would, be discarded, when, so long as the material recovered is properly piled to ensure rapid drying, or, preferably is kiln-dried after conversion, it is perfectly safe to use. On the other hand, if such timber is close-piled when green, any incipient decay present is likely to develop, and fresh infection from spores of the same, or similar, fungi, may occur. Most dote in timber can be traced to bad practices at the mill, or to close-piling of imported timber shipped green (see also discussion on page 169 and below).

Trametes serialis.—A brown pocket rot has been responsible for complaints of dote in Douglas fir, leading to the assertion in some quarters that this timber is less durable than European redwood. Decay takes the form of small, spindle-shaped pockets, of soft, discoloured, dark-brown wood (Plate 54, fig. 1); thin white threads of hyphae may or may not be visible. When the wood has had time to dry out, attack of this nature is often more apparent, because of the development of shrinkage cracks

in the affected zones. Timber containing such visible decay will have lost mechanical strength, and should obviously not be used. The fungus most frequently responsible for this type of infection is *Trametes serialis*, a species common in America, but of rare occurrence in the United Kingdom, unless present in imported timber.

Douglas fir is no more susceptible than European redwood to fungal attack, and the dense form is rather more resistant, but much Douglas fir is imported in a green condition, practically straight off the saw, whereas the Baltic timber is usually stick-piled immediately after conversion, and for some time before shipment. Any fungus present in green timber, and spores that may have alighted on the surface of wet boards, are favourably placed if the material is close-piled on arrival overseas. On the other hand, if properly stacked on landing, the timber would dry out before any fresh decay could occur, and that already present, if not visible when the timber was green, would become apparent during drying, allowing affected wood to be rejected instead of being put into service. *Trametes serialis* is also the most usual cause of dote in Sitka spruce.

Trametes pini.—A white pocket rot is sometimes found in Douglas fir ; it occurs as small elliptical areas ⅛ to ½ in. in length, with pointed ends (Plate 54, fig. 2). Such infected timber is unsuitable for use, but the fungus responsible, *Trametes pini*, is essentially one that originates in the standing tree, and does not spread to any extent after felling.

An unidentified fungus has been responsible for incipient decay in imported ash, beech, and birch ; it usually appears as a white flecking of the surface. When consisting only of much lighter-coloured, small, round or oval, areas that can be removed by planing to a depth of ⅛ to ¼ in., the sound wood beneath is perfectly safe to use. In a more advanced stage, attacked timber is, of course, worthless, *vide* Plate 54, fig. 3. In a still more advanced stage, fine black lines may be visible ; the wood is then very brittle.

There is nothing that the importer or ultimate consumer of wood can do to combat forest fungi other than arresting development of such infection by proper stacking of green timber as received ; it is presumed that all reasonable care will be taken at all times to destroy any timber found to be infected. Provided these two points are observed, forest fungi will not be a problem

FIG. 1. Dote (incipient decay) in Sitka spruce

FIG. 2. White pocket rot in Douglas fir

FIG. 3. White pocket rot in Canadian birch

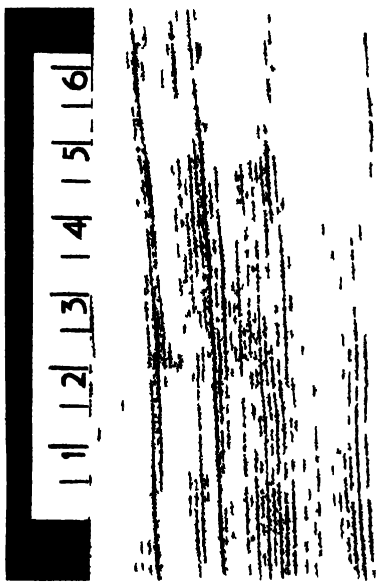


FIG. 4. Resin streaks in Sitka spruce

Photos by F.P.R.L. Princes Risborough

PLATE 55

FIG 1.—*Merulius lacrymans* portion of a decayed joist showing two fruiting bodies, mycelium, and deep cracks along and across the grain

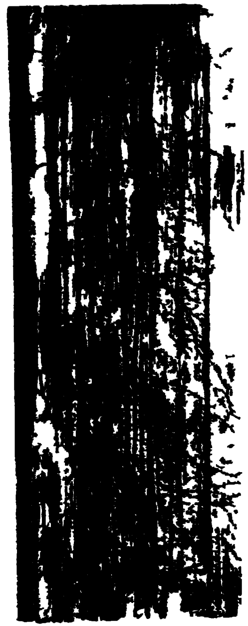


FIG 2. *Coniophora cerebella* portion of a decayed joist showing dark strands of mycelium and longitudinal cracks in the wood

FIG 3. A board of Scots pine showing sap stain fungal infection of the sapwood

Photos by F P R L Princes Risborough

in timber yards. Eradication in the forest is more difficult: sound silvicultural technique and good forest management are the key to minimizing such infection.

Fungi that attack wood in service.—Fungi that attack wood in service may be either "dry rots" or "wet rots". In buildings the former are usually much more serious than the latter, but in coal-mines wet rots are mainly responsible for decay. By far the most important fungus destructive to wood in service is *Merulius lacrymans* (Wulf.) Fr., which will attack drier wood than most fungi, although not wood below about 20 per cent. moisture content. Because of the necessity for adopting appropriate remedial measures promptly, when *Merulius lacrymans* is the causal agent of decay, it is important for all who are responsible for the care of buildings to be able to identify the fungus correctly. It must not be confused with the cellar fungus, *Coniophora cerebella* Pers., which is capable of attacking only definitely wet wood, and is therefore usually not a serious problem. Nor should *Merulius lacrymans* be confused with mould growths that frequently appear as tiny green or black tufts on damp wood. Such moulds do not cause decay, but their presence is indicative of damp conditions, favourable to the attack of wood-rotting fungi.

The most effective method of eliminating wood-rotting fungi from interior wood-work is to use sound, seasoned timber, free from fungal infection in the first place, and to provide and maintain efficient ventilation so that the timber will not be exposed to damp conditions subsequently. Basement conditions call for effective damp-proof courses, both horizontally and vertically. Linoleum-covered floors should be sparingly washed with water, and such floors should be adequately ventilated beneath. If timber is to be laid direct on concrete it should be laid in a bituminous mastic. This is standard practice with wood-block floors, but strip floors are frequently nailed to fillets let into the concrete, leaving a ½ or ¾ in. clearance between the underside of the floorboards and the top of the concrete. This is thoroughly bad practice, and a fruitful source of "dry rot" infection, even with supposedly naturally durable hardwood floors of such timbers as oak or teak. When this type of floor is required, pressure-treated softwood fillets should be used, and the air space between floor and concrete should be filled with a bituminous substance. Such floors tend to be less satisfactory than wood-

block floors: there is a risk of action between the wood preservative and bituminous material, and it is exceedingly difficult to ensure that the air space between the floor and the concrete is completely filled. Any timber built in to brickwork, masonry, or concrete should be recognized as subject to the decay hazard. Unless it can be ventilated all round, only pressure-treated material is really suitable in these circumstances; an open-tank treatment of the ends of long timbers, *e.g.*, joists and bearers, that can be done in a steel drum on the building site, is a possible and practicable compromise. Once rot makes its appearance, it is imperative to take active measures immediately. The causal agent must be identified, and all decayed and infected wood removed and burned. Replacements should be with sound, preferably kiln-dried, material; if recurrence of attack is at all probable, wood preservatives should be employed prophylactically. Lastly, but of the utmost importance, steps must be taken to discover what gave rise to the unsatisfactory conditions culminating in fungal decay, so that these conditions can be corrected before repairs are put in hand.

Wood in contact with the ground, exposed to the weather, or inevitably exposed to fungal infection as in coal mines, must be recognized as having a relatively short life. It is then a simple matter of economics to decide whether the use of more resistant timbers is the correct answer, or whether the use of wood preservatives is the better solution. If the latter course is adopted, then adequate treatments are essential, *vide* Chapter XIV. In general, when the decay hazard is unavoidable, adequately pressure-treated non-durable timbers are usually more economical, and give a longer service life, than the most durable timbers untreated. The descriptions of the different fungi, given in the notes on different species, have been culled from leaflets and bulletins, published by the Forest Products Research Laboratory, to which reference should be made for more detailed information.

Merulius lacrymans (Wulf.) Fr., which is the commonest fungus responsible for "dry rot", is a brown cubical rot. The appearance, both of the fungus and of infected wood, depends on the stage attack has reached, and on the growth conditions for the fungus. In damp conditions the fungus develops as white, fluffy, cotton-wool-like masses spreading over the surface of attacked

wood. In drier conditions the mycelium forms a grey-white felt over the wood, usually with small patches of bright yellow or lilac. Branching strands may develop from the felt, varying in thickness from coarse threads to strands as thick as a lead pencil. These strands are made up of hyphae that conduct water; they can penetrate the mortar of a brick wall, and cross steel-work and concrete to reach new feeding grounds, *i.e.*, as yet uninfected wood. The fructifications are soft, fleshy plates, with white margins (Pls. 53 (*b*) and 55). Numerous folds or shallow pores occur on the surface of a fructification, and contain the rusty-red spores. These are microscopic, and so light that they are easily blown about; they are sometimes produced in such quantities that a whole room may be covered with a rusty-red layer of spores. The fructifications sometimes grow vertically, in the form of a thick bracket, when the pore-bearing surfaces become elongated like small stalactites. Water may be exuded in drops by the fructifications — hence the name *lacrymans* or weeping.

The fruit bodies, which grow out into the air and light, are frequently the first indication of dry rot in a building, but unventilated rooms or shut-up houses that have been infected usually have a characteristic musty odour. Slight waviness on the surface of panelling, or the sinking of a floor, may be the first warning of extensive damage. Infected wood is soft when tested with the blade of a penknife, and it will not "ring" when struck. Wood beneath a coating of mycelium is wet and slimy to the touch, but in the final stages of attack it is dry and friable, brown in colour, and breaks up into cube-shaped pieces.

Poria vaillantii (D.C.) Fr. is a brown cubical "dry-rot", responsible for decay in buildings, but also occurring in coal-mines; it requires the presence of more moisture in wood to initiate infection than does *Merulius*. The final stages of attack are similar in their effect on wood to the action of *Merulius lacrymans*. The hyphae and mycelium of *Poria vaillantii* remain white and soft; the fruiting body is plate-shaped, covered with fine pores, and also white. The hyphae penetrate brickwork, but not deeply, and attack is therefore usually more localized than with *Merulius*.

Coniophora cerebella Pers., commonly called the cellar fungus, is also a brown rot, but not a cubical rot. In the final stages of attack, the wood does not break up into cubes, but develops

long splits or cracks, *vide* Plate 55, fig. 2. This is a fungus that favours decidedly wet conditions, and it is very liable to occur wherever there is persistent water leakage or condensation. The hyphae are always fine; they rapidly turn brown or almost black. The fructification is a thin plate, olive-green in colour. Attacked wood becomes darker in colour, and develops longitudinal cracks that are dark brown or black; cracks at right angles to the longitudinal may also occur, but the cubical breaking down of the wood that characterizes *Merulius* infection is usually wanting. In the final stages of attack, the wood is extremely brittle, and can be powdered in the fingers.

Paxillus panuoides Fr. is a brown rot requiring very moist conditions. The hyphae are paler than those of *Coniophora cerebella*, the mycelium is rather fibrous, and yellow or violet. The fruit bodies, which are often bell-shaped, are olive-green, with deep gills on the under surface.

Phellinus cryptarum Karst. is a white rot, only recorded as attacking oak; it has occasionally been found active in building timbers. The hyphae are white and fibrous; the fructification is a thick, leathery plate or bracket, buff-coloured, with darker brown pores. In the final stages of attack, the wood is reduced to a soft white mass in which the hyphae are embedded.

Lentinus lepideus Fr. is a brown cubical rot, requiring moist conditions. It attacks timber out-of-doors, *e.g.*, telegraph poles, railway sleepers, and paving blocks. The fructification is a brown, woody mushroom. The fungus and decayed wood have a characteristic aromatic odour. Cartwright and Findlay ("The Decay of Timber and its Prevention", H.M. Stationery Office, 1946) record that this fungus "occurs quite frequently on worked timber which has been imperfectly creosoted".

Poria xantha Lind.non Fr. is also a brown cubical rot, requiring moist conditions. It is commonly found in greenhouses. The fructification is a thin plate, yellow in colour.

Of the foregoing, *Merulius lacrymans* and *Coniophora cerebella* are the most common fungi likely to be encountered in wood in service, and the first named is by far the most serious of all wood-rotting fungi, being responsible for untold damage annually. Good constructional design is the best prophylactic measure against ultimate fungal attack, but, where the decay hazard is unavoidable, the choice should be made between the naturally

resistant timbers, or non-resistant timbers adequately treated with suitable wood preservatives, depending on which of these two alternatives is the more economical in the particular circumstances.

Mention should also be made of two fungi, unimportant in themselves, which are nevertheless an indication that dangerously damp conditions exist. Elf cups (*Peziza* sp.), which are yellow-brown cups about 1 in. in diameter, not infrequently develop on plaster ceilings following flooding from defective plumbing or frost damage. Unless steps are taken to secure rapid drying out of the affected areas there is a risk of subsequent " wet rot " or " dry rot " infection. Another fungus that should similarly be regarded as a warning that dangerously wet conditions have become established is a species of inky cap (*Coprinus* sp.). This fungus produces small soft toadstools that dissolve into an inky fluid. Findlay (*Dry rot and other timber troubles*) describes this species as often growing " on damp cellar walls ", but they may also appear on the underside of ceilings saturated by persistent plumbing leaks or defective internal gutters.

THE SAP-STAIN FUNGI

Sap-stain or blue-stain in timber is caused by several species of fungi of the mould type These fungi are distinct from those that cause decay ; hence, " blue-stain " is not an incipient stage of decay, but its presence may be an indication of conditions favourable for the attack of wood-rotting fungi. Moreover, badly blued timber should be suspected of possibly also containing incipient decay or dote.

All staining of wood is not necessarily " blue-stain ". Green timber rich in tannins that comes in contact with iron, as in sawing, may become stained blue-black. This is the result of chemical action, and the stained areas are usually superficial and easily planed off. Similarly coloured stains, caused by sap-stain fungi, penetrate wood deeply and rapidly (Plate 54, fig. 3).

Some wood-rotting fungi cause discoloration, but staining from this cause is accompanied by softening of the wood, whereas blue-stain fungi have little or no effect on strength properties, other than reducing resistance to impact bending, sometimes by as much as 40 per cent., which is of material importance in

timber for tool handles and athletic goods. On the other hand, "blue-stain" is responsible for degrading large quantities of susceptible timbers, because their value is reduced for decorative purposes, and, if heavily stained, they may be unsatisfactory for paint finishes.

Besides the fungi responsible for "blue-stain", there are several other mould fungi that stain wood green, pink, purple, and, more rarely, brown; the majority of these produce a powdery or downy growth of mould that is easily brushed or planed off.

"Blue-stain" in softwoods is caused by several species of the genus *Ceratostomella*; attack is confined to the sapwood. "Blue-stain" in the light-weight, light-coloured tropical hardwoods, such as obeche and ramin, is usually the result of *Diplodia* infection; attack is not confined to the sapwood, but may extend right through a log. Several mould fungi attack the light-coloured temperate hardwoods, not necessarily confining their attack to the sapwood. Ash and poplar are liable to be discoloured a dark brown, and oak a pale yellow.

The discoloration caused by mould fungi is not a stain in the true sense of the word: it is the presence of numerous dark-coloured hyphae in the translucent cells of the wood that produces the tinting visible on the surface. The fructifications are small, black, flask-shaped perithecia, as large as a pin's head, often with long necks, and containing numerous spores.

As with wood-rotting fungi, four conditions are necessary for mould fungi to grow: (1) sufficient moisture (actually appreciably more than is necessary for the more important wood-rotting fungi), (2) food supplies, in the form of starch and sugars stored in the cell cavities, but not the wood-substance of which the walls are composed, (3) suitable temperatures, and (4) oxygen (obtained from the air). The right type of food material in sufficient quantities is a limiting factor. in most softwoods these requirements are only found in the sapwood, but in Sitka spruce attack may spread to the heartwood. The presence of bark saturated with moisture also inhibits mould growth from want of air. Relatively high temperatures are necessary for active growth: the optimum is between 70° and 80° F.; below the optimum, growth is very slow. In temperate regions favourable temperature conditions only exist in the summer months. Reduction in moisture content in the surface layers of wood can rapidly become

a limiting factor: the fungi require moisture contents above the fibre saturation point of wood to initiate attack.

Unless infection has occurred in the forest, rapid reduction of surface moisture in converted timber is the simplest method of inhibiting mould growth. Kiln drying immediately after conversion is the surest safeguard. Piling in properly built stacks, with stickers of maximum thickness, does not always ensure sufficiently rapid drying to prevent staining of particularly susceptible timbers. With these timbers the use of chemical dips is more or less essential, and is standard commercial practice in parts of northern Europe and North America, *vide* pages 262 and 263.

Susceptible timbers will often become infected by sap-stain in the forest after felling, either from the ends of logs or through places where the bark has been removed or damaged in felling. Avoidance of bark injury, and the use of end-coatings, are effective temporary measures, which should be regarded only as auxiliary to rapid extraction from the forest, followed by immediate conversion at the mill. Suitable end-coating materials are hardened gloss oil, containing 10 per cent. of cresylic acid, creosote, tar, or even lead paint. Any areas where the bark has been removed should also be dressed with the material used for end-coating.

Once timber has been dried below the critical stage for "blue-stain" infection, these fungi should not constitute any problem to the consumer. If conditions in service become such that fresh blue-stain infection could occur, conditions favouring the attack of wood-rotting fungi would also exist, presenting a much more serious problem, and one requiring drastic and immediate remedial measures.

CHAPTER XIII

WORM IN TIMBER

The damage referred to as worm in timber is the result of insect activity, but in salt water, teredo or ship-worm, and a form of wood-louse belonging to the crustacean family, are responsible for damage of this type. Insects tunnel in timber, spoiling the appearance of exposed faces, and, if the tunnels are numerous, they may so reduce strength properties as to make the wood valueless. Some insects only attack living trees or newly felled logs, some only seasoned wood, and others only the sapwood of certain species. In consequence, the presence of insect damage is not in itself necessarily a cause for alarm: the damage may be of the first type and therefore of no consequence in seasoned timber, beyond the disfigurement caused. Moreover, some insects and crustaceans commonly associated with timber are of no importance because they do not attack it. For example, the land form of wood-louse is to be found under any piece of wood that has been left in contact with the ground, in sheds, or in the open for any length of time: these are the small oval-shaped crustaceans that roll up into balls when touched. Although probably the most familiar creature associated with timber, wood-lice are of no practical importance, as they do not attack wood. At most they are an indication that storage conditions are not good, and may lead to infection by wood-rotting fungi. On the other hand, dangerous pests are often overlooked because their insignificant appearance results in their escaping notice.

Everyone is familiar with the stages in the development, called a life cycle, of moths and butterflies from egg to caterpillar or larva, followed by a resting period or pupation stage as a chrysalis, until the emergence of the adult moth or butterfly. Few moths attack timber, although some are serious forest pests of standing trees, but other insects that have similar complex life cycles are responsible for heavy losses to timber producers and users.

By far the most important of these insects in temperate climates are beetles, a knowledge of the life cycle of which has indicated the most effective stage for introducing measures of control. Some beetles are destructive in the larval, or feeding, stage, and others do more damage as adult beetles. With the former, the larvae feed on wood, either the substance of which the cell walls are made, or the contents of those cells. With the latter class of beetles the larvae feed on a fungus, introduced by the adult beetle at the time of egg-laying; the fungus, in turn, obtains its nourishment from the wood. Tunnelling, which is the destructive work of " beetles ", is done by the larvae in the first type of pest, and by the adult beetle in the second. With the first, control must aim at killing the larvae before they can get into timber, or, failing this, wood liable to attack should be rendered unfit or unattractive as food for such larvae. With the second type, the adult beetles must be denied access to potentially attractive egg-laying grounds, *i.e.*, usually freshly felled logs, but also standing trees of some species; failing this, control should aim at destroying the fungus, which will at least ensure that any attack in progress will cease. The duration of the life cycle is another important factor in deciding the most suitable method of control; with some insects the life cycle is completed in a few months, but with others it may last two or three to several years. If the life cycle is a long one infestation may have occurred, and the destructive agent have been at work, for a considerable time before it is discovered; in these circumstances methods of control can seldom be applied at a sufficiently early stage to be of practical value. If sterilizing treatments are selected as the control measure, repetition of the treatment must be the more frequent the shorter the life cycle of the pest, because sterilization does not confer immunity from reinfestation. All control measures, but especially sterilization treatments, should be applied when the pest is in its most vulnerable stage, *i.e.*, egg, larva, pupa, or adult, depending on the particular pest involved.

The different types of insects, the means of their identification, and the methods of control, are discussed fully in various pamphlets and bulletins issued by the Forest Products Research Laboratory, Princes Risborough, the Forestry Commission, and other Government organizations. Below, the groups of insects of

importance to timber users are briefly described.

I. Forest and Mill-yard Pests

(1) *Longhorn beetles and certain moths.*—The eggs of these insects are laid in crevices, or just under the bark, of living but usually unhealthy trees, or newly felled logs. The adults do no tunnelling, the damage being done by the larvae, which feed on wood substance. The galleries are ⅛ to 1 in. in diameter, and oval in cross section; they are packed with coarse "**bore dust**" or **frass**. The damage done is considerable, but, except for the house longhorn borer, infestation occurs only in green timber; the larvae may continue feeding in relatively dry wood, but they will not migrate to adjacent seasoned stock. Rapid extraction of felled logs, immediate removal of bark of susceptible timbers, and heat-sterilization of infested wood, will secure adequate protection against most longhorn borers.

The house longhorn (*Hylotrupes bajulus* L.), Pl. 56, fig. 1, & Pl. 60, fig. 3, is a serious pest in parts of northern Europe: in some districts infestation has to be notified, and appropriate remedial measures are compulsory. The pest has long been known here, and has recently become of sufficient importance in some parts of the pine country of Surrey to necessitate Bye Laws requiring timber used in repairs or new work in roofs to be treated with approved wood preservatives. The pest attacks the sapwood of softwoods, and usually only timbers in the roof space. As the life cycle is upwards of 10 years, serious damage may result before the first flight holes bring the attack to light. The frass contains pellets that resemble flints of petrol lighters when examined with a pocket lens. The finding of such frass or oval flight holes is not proof of house longhorn infestation; still less that there is continuing activity. Other longhorn borers produce similar frass and oval flight holes. Active house longhorn borer infestation here has only been found recently in parts of Surrey, and, even there, no *active* infestation has been found in any building more than 50 years of age except where timbers have been renewed much more recently.

Rhagium bifasciatum F. is one of the commonest longhorns in Britain, but it is of little economic importance; it attacks decayed softwoods. *Tetropium gabriele* Weise is the larch longhorn, which confines its attack almost entirely to larch. It is of

common occurrence in England and Wales, and has been responsible for appreciable damage when simple precautions have been omitted. Oviposition may occur in unhealthy trees, but is more usual in sound, felled logs that have been on the ground throughout a summer. The larvae feed beneath the bark, and enter the sapwood for pupation. Oviposition can be entirely eliminated by barking logs when felled.

(2) *Pin-hole borers.*—These pests belong to the families *Scolytidae* and *Platypodidae*; they feed on a mould fungus, introduced by the adult beetles, and not on wood; the fungus grows on the walls of the galleries, which are wholly constructed by the adults and not by the feeding larvae. Little is known of the fungus, which continues to be called **ambrosia fungus** (hence ambrosia beetles), the name first coined by Schmidberger in 1836. The adult beetles tunnel spirally, at right angles to the grain, into living trees and newly felled logs, and lay their eggs in specially constructed " egg-chambers ". At the time of egg-laying they also introduce a fungus into their galleries on which the larvae feed when hatched. The galleries of different species vary from $\frac{1}{50}$ to $\frac{1}{8}$ in. in diameter; they are usually oriented at right angles to the grain of the wood; that is, at right angles to the vertical axis of the tree. The galleries are usually empty, but they may become plugged with resin or other compounds; the walls of the galleries are stained black, and the tunnels themselves may be surrounded by an elongate-oval area of tissue discoloured by the fungus. Pin-hole borers ruin the appearance of considerable quantities of timber, and the galleries may be so numerous as to reduce strength properties appreciably, but attack does not continue in, nor can it spread to, seasoned timber, because the fungus on which the larvae feed requires moisture. Moreover, the whole of the gallery system of these borers is constructed by the adult beetle, so that the damage is usually done before the timber gets to the mill, often before the tree is felled. In the circumstances, the timber merchant can purchase infested timber without fear of the attack becoming any worse than it is at the time he makes his purchase. Wormy grades of mahogany, lauan, seraya, and meranti contain damage of this type. The " shot-holes " referred to in the Empire grading rules [1] are caused by

[1] *Grading rules and standard sizes for Empire hardwoods*, prepared by the Advisory Committee on Timbers, Imperial Institute. See also page 282.

the same type of beetle, referred to as "pin-hole" borers here, and are distinct from "shot-hole" borers of trade terminology in this country and America. Typical "pin-hole" borer damage in a tropical hardwood is illustrated in Plate 56, fig. 2; Plate 55, fig. 2 gives an idea of the difference in size of the galleries of different species of "pin-hole" borers.

II. Pests of Seasoning Yards

The serious pests of timber yards in temperate regions are the so-called **powder-post beetles**, belonging to the families *Bostrychidae* and *Lyctidae*. The larvae of these two families do not live on cell-wall substance, but on the starch content of the sapwood of certain timbers. In this respect, the food requirements of powder-post beetles resemble those of the sap-stain fungi, but, unlike fungi, the larvae have to devour the cells to obtain the starch they seek. The egg-laying habits of the two families of powder-post beetles differ, as do their demands in regard to the degree of dryness of wood favoured for egg-laying.

(1) *Lyctus, or powder-post, beetles.*—These beetles lay eggs in the vessels of wood, and the larvae tunnel about, feeding on the starch contained in the storage cells. The attack is confined to the sapwood of certain hardwoods,[1] it does not occur in the heartwood of any species, although, in emerging, adults may tunnel through heartwood immediately adjacent to sapwood, *vide* Plate 57, fig. 1. The size of the vessels is a limiting factor: they must be large enough to admit the **ovipositor** (egg-laying tube) of the adult female beetle, since it is in the vessels that the eggs are almost invariably laid. The fine-textured timbers, such as beech, with vessels below 0·1 mm. in diameter, are ordinarily immune.[2] Further, the starch content of the sapwood must be sufficiently high for the powder-post beetle to select the timber for ovipositing purposes. Several timbers, with large enough vessels, fail in this respect and, consequently, are immune to attack. Infestation occurs in partially- or fully-seasoned timber.

The life cycle of *Lyctus* from egg to adult beetle is normally

[1] *Lyctus* attack has recently been reported in the sapwood of a softwood, *Pinus canariensis* C. Sm., grown in South Africa.

[2] I have observed *Lyctus* infestation in *Ilex* sp., the vessels of which are not more than 0·05 mm. in diameter, but this is exceptional.

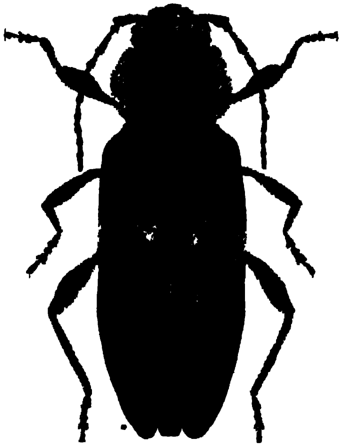


FIG. 1.—The house longhorn beetle ( )

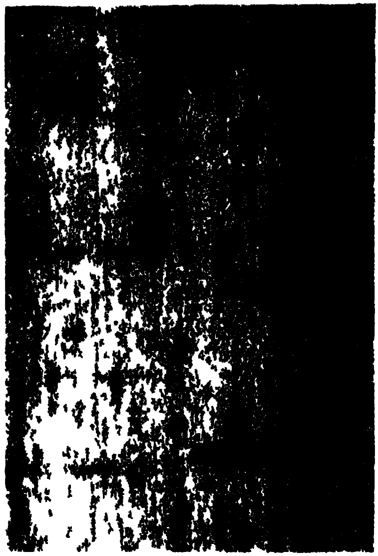


FIG. 2.—Pin-hole borer damage in African mahogany. (Note direction of the galleries at right angles to the grain of the wood.)

FIG. 3.—"Shot holes" in a meranti board (compare for scale with Fig. 2).

FIG. 4.—Subterranean termite damage; wood hollowed out and filled with mud.

Figs. 1, 2 and 3 *photos by F.P.R.L., Princes Risborough*. Fig. 4 *photo by F.R.I., Kepong, Malaya*.

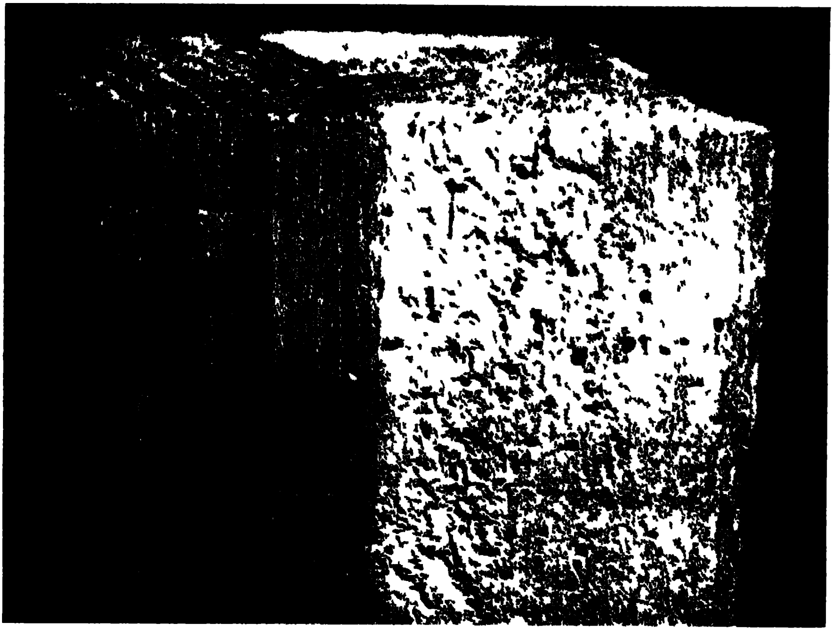


FIG. 1.—Portion of an oak plank showing *Lyctus* attack confined to the sapwood

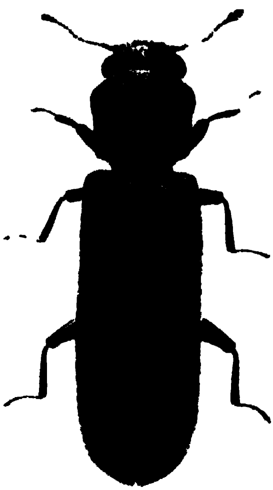


FIG. 2.—*Lyctus brunneus* Steph.
(× 12)

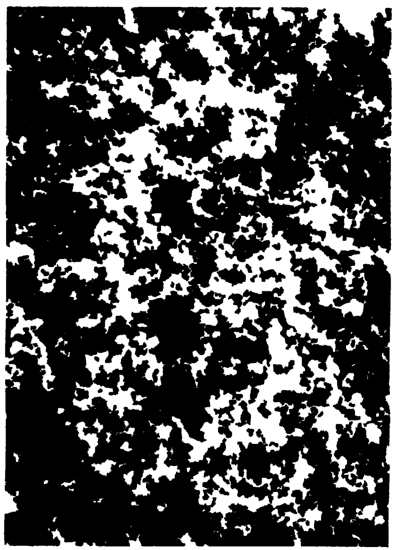


FIG. 3.—*Lyctus* frass

about one year, but the period may be as short as ten months, and, where food supplies are deficient, the life cycle may be considerably extended: to two, or even three to four, years. Adults normally emerge from April to September, appearing in largest numbers in June, July, and August. Immediately on emerging, the adults mate, and the female begins egg-laying, being most fastidious in regard to the suitability of the particular piece of wood selected for egg-laying: it must be rich in starch.

There are several species of *Lyctus*, and the related genus, *Minthea*, the former being cosmopolitan, and the latter tropical. There are four common species of *Lyctus* in Great Britain: *L. brunneus* Steph. and *L. linearis* Goeze being the most abundant. *Minthea rugicollis* Walk. is the commonest species of *Minthea*; adult beetles have emerged in this country, but the species is not known to have bred here.

Soaking of logs in water is known to be an effective means of rendering susceptible timbers immune to powder-post beetle attack, but the soaking period is too long for normal commercial use. Bamboos and thatching materials are, however, regularly soaked in the East prior to use. Experiments have established that the starch content of the storage tissue is reduced by prolonged soaking, and this explains subsequent immunity of soaked materials from powder-post beetle attack. Starch depletion is, however, not the sole factor: laboratory-scale experiments with yellow meranti, a timber normally rich in starch, showed that soaking periods too short to remove noticeable quantities of starch (as determined by the iodine test) were effective in rendering test blocks immune when subsequently exposed to attack. These, and similar experiments, suggest that the presence of some other, and presumably more soluble, substance than starch is essential to induce powder-post beetle attack; the substance or substances have not, as yet, been isolated or identified. Starch depletion can be achieved in this country by storing logs in the shade, with the bark on; the parenchyma cells remain alive sufficiently long to exhaust the stored starch during respiration. Exposed to the hot sun, or in the tropics, parenchyma cells die too quickly from lack of moisture to ensure exhaustion of starch, and there is the added risk during storage of still more serious losses from other forms of insect attack.

The galleries of powder-post beetles are similar in diameter

to those of the smaller "pin-hole" borers. They run along the grain; that is, parallel with the vertical axis of the tree, but, as attack progresses, the separate galleries become merged, and all the attacked wood, with the exception of a thin outer skin, is eventually reduced to a flour-like powder (Plate 57, fig. 1). Powder-post beetles are responsible for enormous damage to the sapwood of susceptible timbers, *e.g.*, ash and oak, probably causing heavier financial losses in British yards than any other insect pest, and they may become a still more serious problem in the future as more and more of the light-weight tropical hardwoods are used as softwood substitutes.

Control of powder-post beetle attack presents many difficulties. The total exclusion of sapwood of susceptible species will secure 100 per cent. immunity from attack; this course is probably only economically justified in first-class joinery, flooring, panelling, and furniture. With structural timbers, the amount of sapwood to be tolerated should be specified, *e.g.*, sapwood not to exceed $\frac{1}{8}$ of the width of any face, and not to occur on more than two faces of any one piece of timber.

Prolonged storage of logs in water, as stated above, is effective in securing immunity from *Lyctus* attack, but the storage period for timber in log form is too long for the method to be practicable. Alternatively, prophylactic measures may be resorted to in an endeavour to secure immunity from infestation during the seasoning and storage period, and prior to manufacture, since it is in these stages that infestation usually occurs. To reduce the risk of infestation in timber yards and factories it is recommended that stocks be inspected twice yearly in March and October, yards should be kept clean and free from accumulating sapwood waste, and only softwood or heartwood piling sticks should be used. Chemical control, by dipping of green timber immediately after conversion, is a practicable solution of the *Lyctus* problem in the United Kingdom up to the manufacturing stage; that is, while timber is in stack for seasoning, or in store awaiting manufacture. The immersion period ordinarily recommended may be sufficient to confer complete immunity from attack of timber dipped in veneer form, but is not effective for dimension timber once the latter is dressed or re-sawn, because surface penetration of the toxic chemicals alone is secured. The transitory nature of the protection is, however, of high com-

mercial importance, where all the evidence points to infestation occurring prior to manufacture: if timber could reach the joinery and wood-working shops immune from infestation, losses from *Lyctus* attack would become of negligible importance in the United Kingdom. Long immersion periods, with heavy absorption of chemicals, are normally uneconomic in this country, but in Australia have been found both necessary and economic; the chemicals used and the sterilization treatments recommended are discussed in Chapter XV.

(2) *Bostrychid powder-post beetles.*—Except for differences in size of galleries, the damage done by these insects is similar to that of the previous group. That is, the larvae tunnel in partially- or recently-seasoned sapwood of certain hardwoods, reducing the wood to a flour-like dust, which is slightly coarser in texture than that of the *Lyctus* group; the galleries and exit holes are up to ⅛ in. in diameter. As with *Lyctus*, damage is confined to the sapwood.

Bostrychid beetles are typically larger than those of *Lyctus* species and they are pests of tropical rather than temperate regions, although there are a few species in temperate climates, including *Apate capucina* L. found in European oak. The adults are characterized by a hooded, roughened thorax covering the head, with a three-jointed club at the end of the antennae. The life cycles of the different species have not been the subject of such critical study as those of *Lyctus*, but it is apparent that the adults will infest timber in an appreciably wetter condition than that favoured by *Lyctus*: I have observed stacks of mersawa heavily infested by a *Bostrychid* beetle within a few days of the timber being sawn, whereas *Minthea* (the commonest of the *Lyctus* group in Malaya) would be unlikely to infest timber until it had been in stick for several weeks.

Bostrychid beetles also differ from the *Lyctidae* in their egg-laying habits: the adults bore into the wood, constructing a Y-shaped egg-tunnel, which is kept free from dust, and in which the female lays her eggs. When the eggs hatch the larvae continue burrowing, but longitudinally, as do *Lyctus* larvae, packing the gallery system with fine, flour-like dust. The methods of control of *Bostrychid* beetles are identical with those for *Lyctus* beetles.

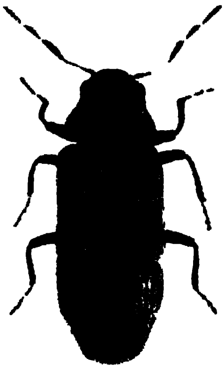
III. Pests of Well-seasoned, Old Wood

Furniture beetles, and the death-watch beetle, belong to the family *Anobiidae*, which are important pests of seasoned wood, although, paradoxically, occurring naturally in decaying stumps out-of-doors. There are several species of furniture beetles, belonging to more than one genus, but the most frequently encountered " indoor " species is *Anobium punctatum* De G. The death-watch beetle is *Xestobium rufovillosum* De G.

(1) *The common furniture beetle.*—The natural home of this pest is out-of-doors, in decayed trees and posts, but it is better known as a pest of well-seasoned softwoods and hardwoods The damage is done by the larvae, which hatch from eggs laid in cracks in the wood, in joints of made-up wood-work, and, more rarely, in old flight holes. The larvae travel along the grain, but as they feed and grow they tunnel in all directions, filling their galleries with loosely-packed, granular frass, which feels gritty when rubbed between the fingers (Plate 58, figs. 3 and 4); the pellets are appreciably thinner than those in longhorn borer frass.

The life cycle and biology of the common furniture beetle have not yet been fully investigated The adults emerge in June, July, and August, and mate, when the females lay their eggs in suitable places ; they will not lay on smooth surfaces. The eggs hatch shortly after they are laid, and the larvae commence tunnelling into the wood, on which they feed. The length of the life cycle is known to be commonly one year, but, as with *Lyctus*, it is no doubt considerably extended when food supplies are not entirely suited to the pest's requirements.

The common furniture beetle is widely known as a pest of old furniture, and of hardwood constructional timbers in period houses, but more recently it appears to have become as common in softwood flooring, shelving, and carcassing in houses of comparatively recent date, *i.e.*, houses built between the wars. It would seem that the timber has to " mature " to attract the furniture beetle, since it is commonly found in houses built fifteen years ago, but not in houses of similar type erected more recently. An even longer period appears to be required to render oak, and possibly other hardwoods, attractive, but accurate information is lacking on such details. I have found the common furniture beetle in oak panelling after thirty years, but rengas in Malaya



Figs. 1 and 2. The common furniture beetle *Anobium punctatum* De G. (× 14 approximately)

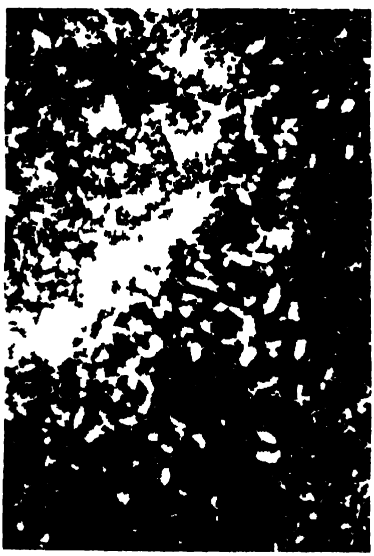


Fig. 3. Frass of the common furniture beetle. (Note typical elongate pellets)

Fig. 4. Damage by the common furniture beetle in a structural timber of Scots pine

Figs. 1, 2 and 4 Crown copyright reserved
Fig. 3 [illegible] Princes Risborough

PLATE 59

Fig. 1. The death watch beetle (× 3 approximately). (Note characteristic bun shaped pellets in bottom right hand corner.)

Fig. 2. Portion of an oak wall plate decayed by fungal activity and attacked by the death watch beetle

was attacked by a different species of *Anobium* within five years. It seems reasonable to infer that slight chemical changes occur in cell-wall substance or infiltrates over a period of years, which render the previously unattractive timber attractive.

In small articles of furniture and wooden ware the damage is not confined to sapwood, but in beams and constructional timbers generally, it usually is. In furniture and small wooden articles the damage done may be quite serious, as, for example, attack in the leg of a chair, but in hardwood constructional timbers attack is mainly confined to the sapwood, and structural damage is only serious when the amount of sapwood is abnormally high. Attack in softwood timbers may develop to the extent of causing some timbers to collapse, if sufficient sapwood is present, but the presence of a beetle population is probably of more importance because of the risk of subsequent infestation of furniture.

Control can be effected by repeated applications of suitable preservatives, particularly those of the solvent type, and by sterilization or fumigation; neither of the last two mentioned methods confers immunity from fresh infestation, but they are more certain in eradicating existing infestation. To reduce the risk of infestation, it is recommended that care be exercised in the purchase of second-hand wooden articles as these may well be infested, thereby constituting a source of infestation for the spread of furniture beetles to sound timber. Fuel logs, and garden woodwork in close proximity to the house, are likely breeding grounds of furniture beetles from which infestation can spread indoors. The galleries of some furniture beetles may be distinguished from the flight tunnels of dry-wood termites (*vide* page 234) by their being plugged with a black substance.

(2) *The death-watch beetle.*—This pest belongs to the same family as the furniture beetle, and its natural home is essentially similar. The beetle lays eggs in crevices, cracks, or old exit holes, and the larvae do the damage by tunnelling in, and feeding on, the wood. Attack is usually confined to old timbers of several species of hardwoods, but it has been known to spread to softwood timbers adjacent to infested hardwoods; attack is not confined to the sapwood, but it is more likely to begin in sapwood than in heartwood. Adequate moisture, and the presence of fungal decay, are conditions favourable for infestation. The galleries made by the larvae are about ⅛ in. in diameter; they

are filled with coarse frass, containing bun-shaped pellets (Plate 60, fig. 1). Removal of decayed wood, and the causes of decay, are the first essential steps in eradicating death-watch-beetle infestation. All too frequently, however, major structural damage has occurred before the infestation is discovered, when replacement of the attacked timbers, rather than *in situ* chemical treatments, is the only practicable course. It is essential to check the construction of attacked buildings, as, although large-sized timbers may have been used initially, subsequent shrinkage may have loosened vital carpentry joints. Moreover, the earlier craftsmen frequently used timbers the wrong way round, so that apparently generous timber sections have been loaded from the commencement almost to the limit of their safe working stresses. Wherever possible, it is preferable to use pressure-treated softwood timber in repairs, but, if for aesthetic reasons hardwoods, and usually oak, must be used, such timber must be well seasoned and free from sapwood. Not infrequently, the elimination of dampness responsible for the initial fungal decay, the replacement of decayed and heavily attacked timbers, and the introduction of steel straps and the like to restore structural stability, will suffice, because any continuing attack will die out when conditions adverse to the rapid development of the beetle are established.

The life cycle and biology of the death-watch beetle have been exhaustively studied by Dr. R. C. Fisher, who concludes that the length of the life cycle " is dependent upon the moisture content of the timber, the presence and extent of fungal decay, and also upon temperature ". Under optimum conditions the life cycle may be only one year, but in less favourable circumstances it may be prolonged over two or more years. Heavy infestation is often accompanied by *Corycorinetes coeruleus*, a steely blue, hairy beetle, which is predatory on the death-watch beetle.

IV. OTHER TIMBER BEETLES

Several other beetles may sometimes be responsible for causing damage to timber in service, but the only two likely to be encountered at all frequently in this country are the wood-boring weevils, family *Cossonidae* and *Ernobius mollis* L. The wood-boring weevils are essentially secondary infestation, following on fungal decay, and, in tackling this, the secondary pest is also

PLATE 60

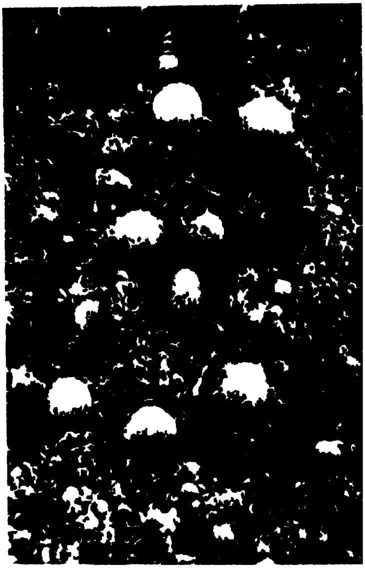


FIG. 1.—Bun-shaped pellets of death-watch beetle frass

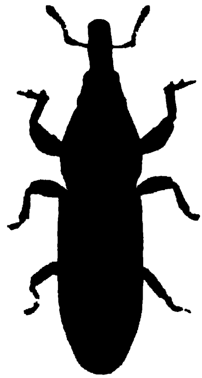


FIG. 2.—The common wood-boring weevil, *Pentarthrum huttoni* Wollaston (× 10)

FIG. 3.—Softwood roofing timber attacked by the house longhorn

PLATE

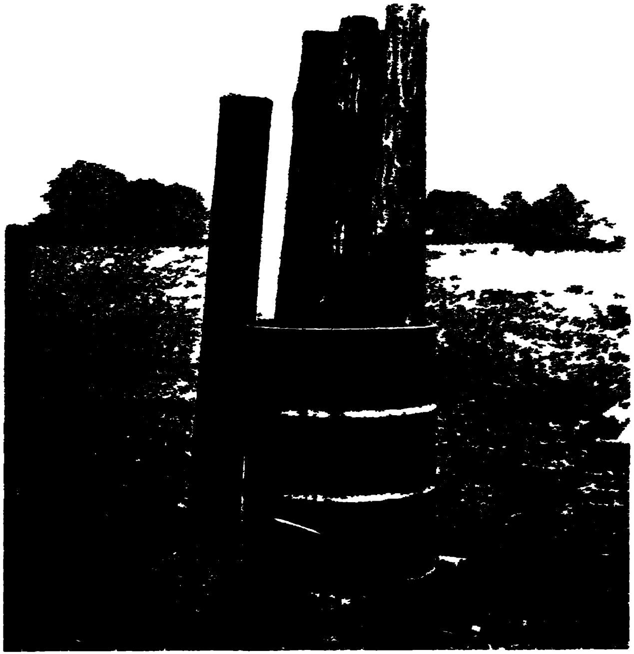


FIG. 1.—Open tank treatment of poles

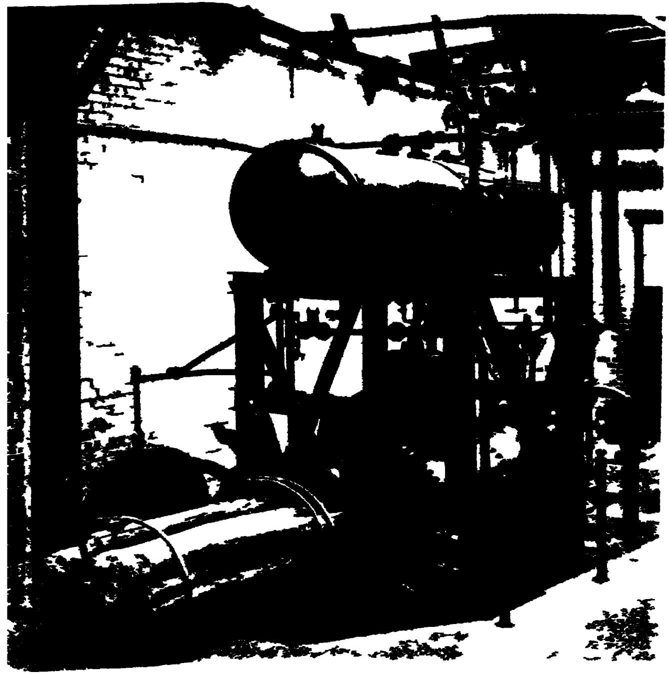


FIG. 2.—... treating plant

eliminated. *Pentarthrum huttoni* Wallaston is probably the commonest wood-boring weevil, and the damage done resembles that caused by the common furniture beetle. The frass or dust is rather finer, usually round, and the conspicuous " snout " of the weevil is a final clue to the pest at work (Plate 60, fig. 2).

Ernobius mollis L. is of no economic importance ; it has not as yet acquired a popular name. It is a reddish or chestnut-brown beetle, up to $\frac{1}{4}$ in. long, which leaves flight holes resembling those of the furniture beetle. The frass consists of small bun-shaped pellets, resembling those of the death-watch beetle but appreciably smaller, which is characteristically a mixture of red-brown and white particles because the larvae feed on bark of softwoods, often just penetrating the outer sapwood. Attack is quite common when the inner bark has been left on the wany edges of carcassing timbers. Removal of the bark brings an attack to an end, and there is no need for any additional chemical treatment. Damage is only likely to result if grounds with bark still adhering have been used as the fixings for panelling. In boring their way out, the adults may leave flight holes that disfigure the panelling, besides giving rise to alarm.

It is important to stress that mere discovery of a flight hole, or even the finding of bore dust, is not necessarily a cause for alarm. It is important to identify the dust before having resort to expensive *in situ* chemical treatments, which, so often, are quite unnecessary because attack has ceased, or, alternatively, substantial structural repairs may be called for and *in situ* chemical treatments will be totally inadequate and probably unnecessary.

The wharf borer, *Nacerda malanura* L., should also be mentioned ; it is a large beetle, superficially similar to some longhorn beetles, which leaves a flight hole about $\frac{1}{8}$ in. in diameter ; attack is confined to decayed timber.

V. Termites

The insect pests discussed in the preceding pages are those that commonly occur in temperate regions ; the same species, or close relatives, and other insects unknown in cooler regions, are pests of timber in the sub-tropics and tropics. In these regions termites or white ants are the most serious insect pests ; they

probably cause more damage to timber annually than do all other insect pests together. Termites also destroy many other commodities, accounting for losses running into hundreds of thousands of pounds annually. Simple control measures exist, which would reduce the termite problem in the tropics to negligible proportions but, paradoxically, effective precautions of any kind are rarely taken.

There are many species of termites, but those that attack timber may be classified into one or other of two broad groups: subterranean termites and dry-wood termites. The former live in large colonies in the ground, and must retain an unbroken covered earthway from the soil to their feeding grounds. There is no risk of attack commencing from the swarms of termites that fly into houses at night; these individuals shed their wings and die by the morning, because they fail to regain a nest before their water requirements can be met. Dry-wood termites live in small colonies in thoroughly seasoned wood on which they feed; they require no access to the soil.

Termites do not make definite tunnels in timber, but they do tend to feed in restricted zones that become packed with mud as attack progresses (Plate 56, fig. 4). Attack on timber in the ground is somewhat different from attack above ground: naturally resistant timbers tend to be gnawed by termites, but the soft, non-resistant species may be completely hollowed out, except for an outside skin of wood. Contrary to popular statements, no timber is immune to subterranean termite attack, but the range in resistance of different timbers is appreciable: exposed to conditions of equal intensity of attack one timber may last less than six months and another more than ten years, with many other timbers with a variable serviceable life between these extremes. Moreover, resistance to fungal decay is not necessarily an indication of resistance to subterranean termite attack. For example, such naturally decay-resistant timber as heartwood oak does not show up well if exposed to termite attack. Conversely, some tropical timbers that are not regarded as particularly durable in their countries of origin, where termites are a more serious problem than fungi, may prove exceptionally resistant in temperate regions, where fungal decay is the serious hazard — examples are kempas and kapur. Hardness of a timber is no criterion of its powers of resistance.

Dry-wood termites invariably feed just below the surface of wood, and in most timbers attack is more or less confined to the sapwood; they produce granular dust, appreciably coarser than that of furniture beetles, which showers out when the sound skin of wood left on the surface of an attacked piece of timber is broken. The feeding termites also push out granular dust through their exit holes, the mounds of this dust often being the only evidence of attack in progress. The flight holes resemble those of some furniture beetles, but they are not plugged with black solid deposits.

Termites need not be nearly so serious a timber problem as they are generally supposed to be, and, of the two types, dry-wood termites are more troublesome than subterranean termites, because of difficulties of control: differences in the habits of the two groups result in precautions for rendering buildings proof against subterranean termites being ineffective against dry-wood termites. Effective control against the former is secured by proper design and construction of buildings: ant barriers must be provided at ground level. The simplest barrier in raised buildings is an oil channel around the feet of posts where they emerge from their foundations; where walls are contiguous to the foundations a strip of metal, extending 2 to 3 in. from the wall face, and projecting downwards at an angle of 45°, let into the damp-proof course below the ground-floor floor joists, is effective. With solid floors it is necessary to provide an impervious floor all over the site: at least 6 in. of concrete, laid on foundations, proof against settlements, and extending through all walls, is recommended. Where these barriers cannot be provided, as, for example, with much timber used in contact with the ground (railway sleepers, fence posts, and poles), no timber will last indefinitely, and the choice is between the naturally resistant timbers or the less resistant ones adequately treated with wood preservatives. Chemical control of subterranean termites, usually involving the introduction of white arsenic powder into the runways, is effective in keeping down the termite population, but it is a palliative and not a curative measure, in spite of claims to the contrary. Extermination of termites by bacteriological methods is claimed for some proprietary products, but investigation of these has failed to establish that they work in any other way than as direct arsenious poisons.

Brush applications of wood preservatives, unless repeated at frequent intervals, *i.e.*, six to twelve months, are not effective in rendering wood immune from subterranean termite attack. Pressure processes are in a different category: with adequate absorptions of suitable preservatives, wood can be made to outlast its mechanical life, *i.e.*, a properly treated railway sleeper will fail from rail-cutting or spike-killing rather than from termite attack or, for that matter, fungal decay.

Dry-wood termites cannot be controlled in the same way as subterranean termites: given a susceptible wood, or exposure to attack, no economic methods exist for conferring immunity from dry-wood termite activity. The pests can be positively eliminated from building timbers and other indoor wood-work by screening buildings with fine metal gauze, a course that is extremely expensive and usually impracticable. Alternatively, reasonable precautions can be adopted that will minimize the risk of dry-wood termite attack, with dependence on curative measures when attack occurs. An American authority recommends the painting of wooden surfaces as an effective method of denying dry-wood termites entry into timber, and where this is practicable the course should be adopted, *e.g.*, for joinery. Planing has been suggested, but this is not an economical measure for carcassing timbers. It seems probable that the total exclusion of sapwood may appreciably delay dry-wood termite attack, even if it does not confer complete immunity.

The nature of the damage caused by dry-wood termites is apt to be misleading; at first sight the damage appears devastating, but closer inspection usually reveals the destruction to be less severe than was thought. In furniture, panelling, and high-class joinery, even a small amount of damage may be serious, because the appearance is spoiled, but in carcassing timbers it is necessary for the damage to be sufficiently serious to weaken the structure before alarm need rise. In practice, dry-wood termite attack is localized — some wooden members may be attacked while adjacent ones are quite free. Moreover, it is usually only parts of such members that are infested, and then often only to a depth of about ½ in. If the infested zone is removed, and the remainder of the timber is liberally dressed with an oil-solvent wood preservative, or even a volatile toxic substance such as orthodichlorobenzene, attack will often cease, and the reduced

member is usually still strong enough to carry the load required of it. It is probable that preparations suitable for eradicating furniture beetle attack will also prove effective against dry-wood termites.

VI. Marine Borers

Although not insects, several marine organisms, of which the teredo or ship-worm is probably the best known, are responsible for heavy losses with timber used in salt water. Intensity of attack varies in different regions, but is generally much more severe in tropical than in temperate climates : even the naturally resistant species such as greenheart and billian may have a very short service life in some tropical waters. The damage done takes the form of tunnelling, either vertically or horizontally, in the wood, which may be so extensive as to destroy the strength properties of a timber member completely.

Any wood used in brackish water [1] is liable to attack, and only in situations where infestation is known to be slight is it economical to depend on naturally resistant timbers. Pressure treatments with capacity absorptions of creosote or other good preservatives have been found effective in temperate waters, but metal sheathing, or studding the timber with nails, are likely to prove more economical wherever marine borers are particularly active. These aspects are discussed in Chapter XIV. Many, but not all, of the timbers that are resistant to a greater or less degree to marine borer attack have been found to contain silica deposits in their storage tissue. Some timbers containing appreciable quantities of silica, however, have not revealed any particular resistance when exposed to attack.

[1] There is some evidence to suggest that water can be too salt for optimum development of the teredo, whereas very low concentrations have been found to be associated with exceptionally heavy infestation.

CHAPTER XIV

THE PRESERVATION OF WOOD

GENERAL PRINCIPLES

Although no timber is immune to deterioration and ultimate disintegration if exposed for a sufficiently long period to ordinary atmospheric conditions, the serviceable life of individual pieces of wood varies considerably, depending on the species concerned, the amount of sapwood present, the use to which the timber is put, and the situation and atmospheric conditions to which it is exposed. For example, sound wood has been recovered from the Egyptian tombs and from piles driven into mud hundreds of years ago; in these, and similar instances, preservation is to be attributed to protection from the atmosphere rather than to inherent durability of the timber used. There is no doubt that many species generally considered non-durable would last indefinitely under such conditions. The persistence in the forest for several centuries of sound stumps of western red cedar is, however, only explained by the natural durability of that species when exposed to ordinary atmospheric conditions. On the other hand, even the most durable timbers may last only a few years if placed in a warm, damp, and badly-ventilated position.

The principal causes of deterioration of wood in service, as distinct from deterioration during seasoning, are fungal infection, termite and other insect or marine-borer attack, mechanical failure, and fire. The resistance of a timber to these agents of destruction may frequently be increased by the use of a suitable chemical, applied as a preservative. One or two substances were used for this purpose as long ago as Roman times, but the extensive use of wood preservatives is a development of the last hundred years. In practice, preservatives are usually applied to non-durable timbers so as to render the treated wood sufficiently resistant to the agents of deterioration to warrant its replacing a naturally durable, but more expensive, timber. The chemicals

used are legion, and several methods of application are advocated. The selection of the most suitable chemical and method of treatment are of the utmost importance and must be based on a thorough understanding of the scope and limitations of preservative treatments; none confers complete immunity, and a treatment suitable for one particular set of conditions may be useless for others.

FIRE-PROOFING

Wood is highly combustible but non-inflammable; that is, although in favourable circumstances any wood may be burnt to ash, timber is, comparatively speaking, not readily ignited. This statement applies equally to the most resinous species and to those furnishing the poorest firewood. Certain timbers are classed as fire-resistant under the London County Council Bye-laws; such timbers have withstood a standard flame test, or have shown themselves capable, under certain conditions, of resisting the passage of flame during a definite, arbitrary period.

Wood heated to a temperature of about 250° C. will decompose, producing inflammable gases and charcoal. This is what happens when the surface of wood is exposed to a flame or to radiant heat. If the inflammable gases are produced in sufficient quantities and ignited, their combustion raises the temperature of wood further in, and, in consequence, the fire is kept going until all the wood is ultimately completely consumed or burned.

Timber above a certain critical thickness, which is of the order of ½ in., cannot support self-maintained combustion, and continued burning is only possible so long as the surface receives an additional heat output from some radiant source such as the flames of a neighbouring fire. The formation of charcoal on the outside of a piece of wood probably acts as a screen against radiant or conducted heat, thereby retarding distillation of inflammable gases from within. In consequence, the rate of burning is much reduced, and, when the layer of charcoal is sufficiently thick, burning may become so slow that insufficient heat is produced to continue the decomposition of wood further in, and the fire goes out. This is what happens with timbers of large dimensions, and explains why, in quite large fires, heavy timber posts and beams often survive when a building is otherwise completely gutted by fire.

The low thermal conductivity of wood has an important bearing on the way burning wood transmits a fire. Some of the heat produced is immediately radiated outwards, some is absorbed in raising the temperature of wood just inside the burning area, and the remainder is conducted to the opposite face, whence it is radiated. Further, the behaviour of flames is important. They rise upwards, and therefore transmit more heat to wood above the source of the flames than to that below or to the sides. Hence, wood held vertically and ignited at the bottom will burn more readily than the same wood ignited at the top or held horizontally. This explains why doors, panelling, and other vertically disposed timbers constitute a greater fire hazard than beams and floors (the greater size of beams and floors is also in their favour).

So-called " fire-proofing " processes are effective in so far as they prevent flaming of the inflammable gases, or combustion of the charcoal: they do not prevent chemical decomposition of the wood, but they alter the form that this decomposition takes. They are, therefore, fire-retarding rather than fire-proofing processes. Gay-Lussac postulated certain theories regarding the action of " fire-proofing " salts as long ago as 1821, and these theories, enlarged upon by subsequent workers, have been generally accepted until quite recently. It was held that suitable chemicals acted in one or more of the following ways :

(1) The chemical melts at a temperature below that at which wood decomposes, forming a glaze over the surface and preventing access of oxygen to the wood.

(2) The chemical decomposes under heat, yielding non-inflammable gases that dilute the inflammable gases from the decomposing wood sufficiently to produce a non-inflammable mixture.

(3) The chemical vaporizes at relatively low temperatures, absorbing sufficient heat to prevent the temperature of the wood rising to the critical decomposition point. This is the action of water on a fire : it requires more than six times as much heat to turn boiling water into steam than is required to heat the same volume of water from 60° F. to boiling point. Heat dissipated in this way makes less available for continuing the chemical decomposition by burning of whatever else is " on fire ".

Recent research indicates that the efficient fire-retardant chemicals for the treatment of wood are those that, under heat,

increase the yield of solid charcoal and water vapour at the expense of inflammable vapours responsible for flaming. The inflammable gases are produced in insufficient quantities to provide an inflammable mixture, so that the treated timber does not flame, and the denser charcoal is so modified that it does not glow under normal conditions. The action, being a chemical one, depends for its efficiency on intimate contact between the fire-retardant chemical and the wood. In practice, this calls for impregnation of the wood, usually under pressure, with a solution of the chemical: brush applications are altogether too superficial to be of any value. Large-size timbers cannot be completely impregnated, but an average penetration to a depth of 1 to 1½ in. is desirable. The alternative, of copious brush applications, essential for timber *in situ*, is much less effective than treatments under pressure.

Several chemicals could be expected to act in the way mentioned above, but for reasons of cost, and such other factors as corrosion, hygroscopicity, and toxicity, selection of a fire-retardant for wood is narrowed to two or three: monammonium phosphate, boric acid, borax, mixtures of these, and diammonium phosphate.

For timber *in situ*, fire-retardant paints confer some degree of protection, and are probably to be preferred to brush applications of aqueous solutions of fire-retardant chemicals. These "paints", which are really plasters, function as an insulating and reflecting layer; they do not control the chemical breakdown of wood under heat. The paints may consist of a thin mixture of calcium sulphate plaster, or sodium or potassium silicate with an inert filler. The following formula for a fire-retardant paint has been proposed in B.S./A.R.P. 33:

Sodium silicate	112 lb.
Water	100 lb.
Kaolin	150 lb.

Such paint should be applied either by two brush coats or by a spray, to give a covering of 20 to 25 sq. yards to the gallon. This, and other fire-retardant paints, have a limited practical application: they offer practically no protection in the event of an intense fire, they are not durable under exposed conditions, and they cannot be applied to timber already painted with an oil paint.

Notwithstanding its combustibility, wood is, and always will be, an essential constructional material. Its specific heat is relatively high, and its conductivity is low: by comparison, most metals require less heat than wood to raise their temperature any given amount, and they conduct heat more rapidly. Hence, wood is often effective in retarding the rapid spread of a fire. Moreover, initial failure of constructional wood-work in a fire can usually be traced to the phenomenon of shrinkage. Wood, like other materials, expands when heated, but this expansion is more than offset by shrinkage of the wood consequent upon the loss of moisture from the fine cell-wall structure. Shrinkage may result in built-up timber, *e.g.*, panels and styles in a door, pulling apart, thereby providing gaps through which flames can pass before the wood itself is consumed. On the other hand, the delay, compared with the rapid transference of heat by conduction through metal barriers, is sometimes sufficient to enable a fire to be got under control before serious damage has occurred.

A combination of different factors results in all-timber dwellings actually constituting a smaller fire risk, from the insurance standpoint, in America, than dwellings constructed of alternative materials. The timber house is naturally better insulated than a brick one, and, in consequence, does not call for excessive strain on the heating system to maintain comfortable conditions indoors, and over-straining of heating systems, to make good heat losses through walls and roof, is a fruitful cause of fires. Another source of fires in dwellings is a defective flue. With any reasonable standard of construction, chimney flues are completely isolated from the timber frame in an all-wood house, and, consequently, defects developing in flues are less likely to give rise to fires in timber dwellings, compared with brick structures, where the same precautions are not taken, and the brickwork supporting joists, etc., is of necessity bonded to the brickwork around flues.

Because of the tendency for wood to char, rather than burn rapidly itself, " heavy-timber " construction is often preferred in America to unprotected steel framing, when the fire hazard is unavoidably high; the burning contents of a building produce heat sufficient to cause steel framing to buckle, resulting in collapse of the building and a total loss, whereas charring of heavy timbers delays collapse, often enabling the fire to be got under control before the timber members have been so weakened that

they are liable to fail, and the building, if not its contents, is saved. "Heavy-timber" construction can seldom be considered in this country because of the relative high cost of large-sized timbers.

The scope for fire-retarding treatments in non-timber-producing countries is, for economic reasons, strictly limited. Ordinarily, sound constructional technique, the use of fire-stops (pieces of wood or incombustible material) to seal off floors and partitions, and insistence on seasoned timber, properly framed together, for joinery and interior finishings generally, will meet all normal requirements. Bye-laws require the use of so-called fire-resistant timbers for certain purposes. Selection of such timbers in other circumstances is, however, seldom justified : if timber is suitable, other factors than the fire hazard should govern choice of species. Precautions against incendiary bomb attack introduce abnormal factors, when fire-retardant treatments may have a very real application. Joinery and finishings in ships, exhibition woodwork, and stage scenery, on the other hand, are in a different category, and even when the regulations do not call for fire-retardant treatments, their use is generally to be recommended. Wherever laminated-wood construction is an economically sound method of construction, as it is today in many timber-producing countries, the extended use of fire-retardant chemicals under pressure would appear to be fully justified.

MECHANICAL WEAR OR FAILURE

In many situations the life of timber is limited by mechanical wear, against which ordinary preservative treatments are ineffective. The serviceable life can sometimes be extended, however, by attention to design, and the selection of the most suitable timber in the first instance. Experience has shown, for example, that for flooring blocks, subjected to an abrasive action, quarter-sawn (edge-grain) timber has a longer life than flat-sawn timber, and paving blocks usually last longer when laid on a resilient, rather than on a rigid, foundation. The corrosive action of sulphuric acid and hydrochloric acid fumes is sometimes regarded as a special form of mechanical wear. Timber brought into contact with hydrochloric acid gas fumes may be seriously weakened in a surprisingly short space of time, and the action of sulphuric acid

on wooden cases of storage batteries is well known. Ordinary preservatives are ineffective against such forms of corrosion, but protection may be afforded by impermeable coatings of wax or other suitable material. A few timbers, *e.g.*, abura and southern cypress, are relatively acid-resistant, and would probably prove more economical than the usual constructional timbers in positions subject to the slow action of corrosive substances. Where corrosive action is rapid, protection of timber by a mechanical barrier, such as wax or a suitable paint, is likely to prove more effective than dependence on the natural resistance of a few timbers to acid fumes.

WEATHERING

Another aspect of mechanical wear is the weathering of timber exposed to the elements. The constant wetting of the surface of wood by rain, followed by rapid drying when the sun comes out, results in checking and deterioration of the wood surface, which increases the hazard of infection by decaying agents, in the main wood-rotting fungi. Checking and slow disintegration of the surface constitute weathering; decay, which may follow, is a secondary condition. Hence, a mechanical barrier is essential to combat weathering, and for this a good oil paint is best. It is important to maintain such a surface, by regular renewal, before the paint film breaks down. The toxic properties of wood preservatives offer no protection against weathering, and such substances are, therefore, of no avail unless they also provide a semi-permeable or impermeable film as a mechanical barrier to the action of the elements. Weathering can occur, and persist for a long time, without decay developing: siding of buildings in Iowa that has never been painted has weathered, but is still quite serviceable after eighty years.

COMPRESSED WOOD

The development of synthetic resin-forming chemicals, phenol-formaldehyde mixes, has opened up a new field for the chemical treatment of wood. The principal use with wood products is to increase the stability of wood against shrinkage and swelling, but synthetic-resin treatments also significantly improve certain mechanical properties. For example, impregnation of maple to

the extent of 20 per cent. of the dry weight of wood, besides reducing shrinkage and swelling permanently, has been found to increase side-hardness by 40 per cent. over untreated wood. Such chemical treatments have a limited application: their effectiveness depends on the resins being deposited in the fine cell-wall structure; they are, therefore, only suitable if applied under pressure. Treatments to increase side-hardness would appear to have economic possibilities for such special purposes as flooring subjected to exceptionally heavy traffic.

Several kinds of compressed wood have been developed in recent years. **staypak** is wood compressed at sufficiently high temperatures and moisture contents to cause the lignin to flow, thereby relieving internal stresses. It is stated to have advantages over densified wood (**improved wood**), and resin-treated compressed wood (**compreg**), in that although it will swell appreciably under conditions that cause swelling in wood, it will return to practically the original compressed thickness on drying to the original moisture content. Improved wood is wood compressed under conditions that do not cause flow of the lignin cementing material in the cell-wall structure; it may be made from solid wood or veneers preferably assembled with a synthetic resin glue. Compreg is resin-treated wood that is stabilized in the compressed form by the resin; the process has been applied to veneers.

Staypak, improved wood (whether made from solid wood or veneers), and compreg can hardly be considered as "wood"; they are manufactured products, the raw material for which is wood. In consequence, it is not surprising that these products have special properties not to be found in ordinary wood. In addition to improved stability, the strength properties are not unnaturally very considerably increased, compared with untreated wood, rendering compressed wood suitable for a variety of new purposes, besides being a superior product for certain old uses. The treatments, and the chemicals used, however, make the resultant product relatively costly. The various forms of compressed wood were of special value for meeting war needs, when cost was often a secondary factor, and for such articles as aeroplane propellers they will fill peace-time requirements. There does not, however, appear to be unlimited scope for these products, and they are no substitute, nor a practicable process for the treatment of wood, to be used as timber.

FUNGI AND INSECTS

Wood preservatives are used mainly to increase the resistance of timbers to insect attack and fungal infection; they are also used in the elimination, or control, of attack in progress, an aspect already referred to in Chapters XII and XIII. Many substances have been tried as wood preservatives; some have proved excellent and others worthless, but none can claim to be the best in all circumstances.

THE PROPERTIES OF PRESERVATIVES

It is important to keep in mind the special circumstances of each particular job when selecting a wood preservative. For example, a substance that is readily soluble in water may be excellent for indoor use but worthless for outside work, and, conversely, a substance with a pronounced odour may be quite satisfactory for outdoor work but totally unsuitable for indoor use. Extravagant claims on behalf of proprietary products should always be accepted with reservation; even the best preservative only prolongs the life of wood, it does not confer immunity from attack for ever.

The ideal wood preservative has yet to be found, but the properties desirable in such an agent may be enumerated, and are useful as a basis for comparison. It should be: [1]

1. Highly poisonous (toxic) to fungi and insects.
2. Readily penetrating into wood.
3. Chemically stable (*i.e.*, not readily volatilized or easily decomposed, and, for outdoor use, not easily leached out).
4. Easy to apply and not dangerous or harmful to those applying it or subsequently handling the treated timber.
5. Non-deleterious in effect on the timber treated.
6. Cheap and readily obtainable.
7. Non-corrosive to iron, steel, or other materials, according to circumstances.
8. Fire-resistant, or at least not liable to increase the inflammability of wood (this is of secondary importance in timber for fence posts, gates, and other similar purposes).

The following additional qualities are sometimes important, especially for indoor application:

9. Odourless.
10. Colourless and free from effect on subsequent painting or finishing processes.

The first three properties are essential qualities of any wood preservative, and the remainder are of diminishing importance, according to circumstances.

CLASSES OF WOOD PRESERVATIVES

In general, existing preservatives may be divided into three classes: (a) the tar-oil group, *e.g.*, creosote, (b) water-soluble salts, *e.g.*, zinc chloride, silicofluorides, arsenic salts, copper salts, and (c) solvent-type wood preservatives in which the toxic substances are dissolved in certain spirits or other volatile liquids.

Some preservatives consist of mixtures of two or more classes, and, in addition, there are volatile substances, the vapour of which is the toxic element.

(1) **The tar-oil group of wood preservatives.**—In this group is creosote, a complex substance derived from coal or wood distillation. The toxic elements are frequently phenolic bodies, but it is apparent that several of the other 200-odd constituents may possess valuable toxic properties: some creosotes poor in phenolic bodies are quite good wood preservatives. Not all "creosotes" are equivalent in quality: some are the products of prolonged distillation that leaves only high-boiling tars of low toxic value. Coal-tar distillates are likely to be superior to wood-tar derivatives. To ensure a good grade creosote it is advisable to purchase on the basis of some accepted standard: in this connection the British Standards Institution specification No. 144 of 1936, or the Australian draft specification No. K.55, ensure high-grade preservatives. The former specification defines three types of creosote, two being the products of distillation from vertical retorts (types A2 and B), and one from horizontal retorts (type A). Service tests have failed to prove that any one type is superior to the others: type A is the heaviest. Creosote is sometimes mixed with Diesel oil where the latter is appreciably cheaper. Provided adequate absorptions are secured, the mixture can

effect worth-while economies in certain circumstances, *e.g.*, for railway sleepers limited in life by rail-cutting. Tests with mixtures in ratios of 75 per cent. creosote and 25 per cent. Diesel oil, 50/50, and 25/75, have established that reducing the percentage of creosote reduces the efficacy of the preservative. There is some evidence that the addition of fuel oil reduces subsequent splitting of the treated wood.

Although conforming to standard specifications, creosotes prepared from different coals vary in cleanliness, and in the amount of sludge produced when mixed with fuel oils. One firm in the tropics imported creosote from Scotland because cleaning of the tankers in which the creosote was delivered was least costly with this particular creosote. Many creosotes are sold under proprietary names: some of these preservatives are excellent and others less so; greater cleanliness, and their being marketed in convenient one-gallon or smaller quantities, are the special merits of the best of these products, which tend to be very much more costly than non-proprietary creosote.

(2) **Water-soluble salts.**—The common water-soluble wood preservatives include zinc chloride, sodium fluoride, and magnesium silicofluoride. Salts of copper, potassium, and arsenic are also extensively used, and borax. Some of these salts are essentially fungicides, whereas others are more suitable as insecticides: copper salts are good fungicides, and arsenic preparations are good insecticides. Sodium pentachlorophenate, manufactured by Monsanto Chemicals Ltd., has given very good results as a fungicide when used as a 5 per cent. solution in water, it is marketed under the registered name of "Santobrite", or as "Cuprinol" for brickwork. When purchased direct from the manufacturers, it is likely to prove the most generally useful, inexpensive fungicide in conditions where *in situ* application of a water-soluble preservative is appropriate.

Several proprietary water-soluble preservatives are available which are useful for small jobs. For larger programmes, it is obviously more economical to purchase the appropriate chemicals for dissolving in water on the site, in preference to buying ready-made solutions containing a high percentage of water on which distribution and freight charges are incurred.

Certain patented water-soluble wood preservatives employ two water-soluble toxic salts, and an oxidizing agent, with the

object of depositing insoluble forms of those salts in the wood. The toxic salts are usually water-soluble copper and arsenic salts. Service tests of certain of these proprietary products have given encouraging results. As with any preservative, however, an adequate treatment is essential. Preservatives of this type are not ordinarily marketed to the public. Instead, the firms manufacturing the chemicals undertake the treating of timber under pressure in their own plants, or, alternatively, they supply the chemicals to firms owning approved plants, and the latter carry out the treatments, furnishing those who supply the chemicals with records of each treatment process. The Celcure and Tanalising processes are operated in this way in this country.

The special application of these and similar treatments is as an alternative to creosote, when resistance to leaching is important and freedom from odour and a paint finish are required They are likely to be more economical than creosote when treatments are carried out at great distances from production centres because freight charges are incurred on the toxic ingredients only and not on the non-toxic solvents, be these water or oils. It must not be overlooked that timber pressure treated with water-soluble salts has a very high moisture content immediately after treatment and must be dried before being put into service ; for many purposes this may entail kiln drying after treatment to obviate delays in the building or repairs programme.

A recent development i the use of a new form of boron of high solubility named "Timbor", produced by Borax Consolidated, Limited, which is being extensively used in New Zealand and Australia. The treatment has to be applied immediately after conversion from the log, the converted timber being dipped in or sprayed with a very strong solution of boron and then covered up to permit of penetration of boron by diffusion, when excellent penetration, even of the heartwood, is secured.

(3) **Organic solvent wood preservatives.**—These consist of toxic substances soluble in refined paraffins (and other petroleum oils) or white spirit ; they are more expensive than water-soluble preservatives because of the higher cost of the solvent. Experiments indicate that permeability of this group of preservatives is usually good and most are reasonably permanent for both interior and exterior use ; they are usually non-creeping once the solvent has evaporated and the treated surfaces can generally be painted

when dry. Most have a strong odour and taint foodstuffs even without the food being in actual contact with the treated wood. The solvents are inflammable, and some have dangerously low flash points, calling for especial care in use and in storage.

The spirit solvent preservatives are quick drying and the solvents usually have a less persistent and objectionable odour than the petroleum oil products. The latter especially may be detrimental to polished surfaces and, because of the fumes given off, masks and goggles should be worn when spraying. With the solvents at present in general use, it is possible that the spirit solvents have better penetrating qualities, but the oil industry is constantly conducting experimental work, which may provide "oils" with better and better penetrating qualities. Oils are cheaper than the spirits as solvents.

The oil-solvent preservatives are of three distinct types: those whose toxic ingredients are wholly volatile, although complete volatilization may be prolonged over a period of two to three years, those whose ingredients are non-volatile, being retained more or less permanently in the wood, and those that include both volatile and non-volatile toxic ingredients. Quite apart from differences in merit of the many toxic ingredients used in oil-solvent preservatives, the class of product that should be used depends on the nature of the problem: eradication of active "insect" infestation necessitates the use of a preservative containing volatile ingredients. If there is no risk of recurrence of infestation, and, assuming adequate, effective penetration, volatile substances alone suffice for dealing with an outbreak. For purely prophylactic purposes, that is, as insurance against possible future attack, whether by insects or fungi, and in combating fungal attack in all circumstances, the non-volatile toxic ingredients are the effective ones. Where active beetle attack is involved, a preservative containing both volatile and non-volatile ingredients is usually advisable: it is seldom possible to ensure complete penetration of the wood, and hence destruction of the pest in all stages, in one application, and the likelihood of re-infestation from any beetles that survive, or from an outside source at some later date, is usually appreciable.

Orthodichlorobenzene and paradichlorobenzene, and, more recently, the "Gammexane" group of products (containing gamma BHC) are known to be highly effective volatile substances

D.D.T. has been added to some commercial formulae. Pentachlorophenol and copper naphthenate are examples of "permanent" toxic ingredients. In choosing a proprietary product, it is essential to know to which of the three categories discussed above a particular preservative belongs. Formulae of proprietary products tend to be changed from time to time, which may invalidate the significance of test results from Governmental laboratories—there is a constant search for cheaper solvents, some of which are not capable of retaining in solution the requisite proportions of the valuable toxic ingredients. A 5 per cent. solution of pentachlorophenol in an oil solvent is the cheapest type of oil solvent preservative for us as a fungicide or for prophylactic purposes, and "Gammexane" emulsion concentrate in 20 volumes of odourless kerosene is the cheapest form for *in situ* use as an insecticide. A 5 per cent. solution of pentachlorophenol in white spirit should be used when creeping of the oil or staining must be avoided.

(4) **Volatile substances, fumigants, and sterilization.**—Other chemicals have an important place in prolonging the life of wood. These are substances that volatilize at ordinary temperatures, or that can easily be converted to a gaseous state. They are more strictly fumigants, rather than wood preservatives, since they are not retained in the wood, and, therefore, confer no protection against subsequent attack. Moreover, their use is essentially restricted to control of insect, not fungal, activity. Against active attack, they are effective, but their transitory character must be appreciated: they should not be regarded as "wood preservatives".

Kiln treatments must be considered as alternatives to fumigation, or to the use of volatile chemicals. Where kiln facilities exist, and the timber is such that it will not suffer from a kiln-sterilization treatment, the method is to be recommended because of its 100 per cent. efficacy when properly carried out. Moreover, kiln sterilization is effective both against fungal activity and insect infestation, whereas fumigation deals only with the latter. A temperature of 160° F. and 100 per cent. relative humidity, held for two hours, would be lethal to fungal infection and insects in timber up to 3 in. in thickness, but these conditions would be too severe for most manufactured wood-work. Temperatures as low as 115° F. and a relative humidity of 60 per cent., held for 36 hours, have been found effective for sterilizing *Lyctus*-infected

timber; allowing for the lag period in heating up the wood to the temperature of the kiln, and a margin for safety, 46 hours for 1 in. material, up to 60 hours for 3 in. timber, are suggested as maximum periods. It seems probable that a temperature of 130° F. and 80 per cent. relative humidity, with a total exposure period of 2½ hours for 1 in. and up to 7 hours for 3 in. material, will prove adequate against any form of insect infestation, but this has not yet been conclusively tested. Neither French polish nor turpentine varnish finishes are appreciably affected by a temperature of 130° F. and a relative humidity of 80 per cent., nor is plywood bonded with resin, casein, or blood-albumin glues for the periods necessary for sterilization. A table of alternative temperatures and relative humidities for the successful sterilization of *Lyctus*-infected timber is given in Forest Products Research Laboratory Leaflet No. 13.

Next to kiln sterilization, fumigation is the most effective means of eliminating active insect attack, whether in the egg, larval, or beetle stage. Portable articles are fumigated in special chambers; skilled operators are required to carry out the work because of the poisonous nature of the fumigants. The fumigants in general commercial use are hydrocyanic acid gas (hydrogen cyanide or HCN) and methyl bromide. Hydrogen cyanide is obtainable as a liquid, which has to be volatilized by suitable means, or the gas may be produced as a result of chemical reaction, inside the fumigating chamber. Fumigation is essentially a task for the expert, since so many factors are involved: in the gaseous state the substances may be harmless to polished surfaces and fabrics, whereas in the liquid state they may do considerable damage. Fumigation with hydrogen cyanide in the United Kingdom is governed by the Hydrogen Cyanide (Fumigation of Buildings) Regulations, 1938.

The application of toxic chemicals that volatilize readily at ordinary atmospheric temperatures provide yet another method for combating active insect infestation. Chemicals such as orthodichlorobenzene belong to this group. The efficacy of these chemicals depends on the poisonous fumes reaching the insects in sufficient concentration to be lethal. It is usually necessary to time the application appropriately, *i.e.*, when the larvae are feeding or the adults are about to emerge. Further, it is advisable not to depend on a single treatment, but to repeat the application

at the first signs of renewed activity. The difficulty of ensuring penetration of the fumes has to be overcome: a fountain-pen filler, small oil-can, or even a hypodermic syringe, to inject the liquid into flight holes or galleries, will ensure better penetration than surface applications. In addition, however, copious surface dressings should be applied to infected areas, and particularly in cracks, crevices, and joints. Many readily volatile substances are not suitable for use in inhabited rooms, because their fumes, if not actually poisonous to man, may induce sickness. Spirit-soluble preparations must, of course, be kept away from flames.

THE TOXICITY, PENETRATION, AND PERFORMANCE OF WOOD PRESERVATIVES

There are, as yet, no British standards relating to wood preservatives other than B.S. 144 for creosote, but in B.S. 1282 *Classification of wood preservatives*, issued in 1945, it is stated that it has been decided to start work on similar specifications for other types of wood preservatives and that it is hoped that these specifications will be available shortly. The following are given as the all-important factors determining the efficiency for wood preservative:

1. Toxicity or killing power towards wood-destroying fungi or insects or both.
2. Penetrating power.
3. Performance, *i.e.*, resistance to leaching, evaporation, and chemical decomposition.

Laboratory tests are available for measuring toxicity, but satisfactory means for measuring penetrating power and performance are difficult to devise. Penetration is particularly difficult to determine with preservatives of the tar-oil group: even on a freshly-cut surface the oil spreads so rapidly that it is difficult to differentiate penetration from surface-spreading from excess preservative in the cell cavities on the periphery of the cut section. Exposure tests, using the same species of timber, and as nearly matched material as possible, for a series of tests, provide a yard-stick for measuring the relative merits of different preservatives. Unfortunately, it is difficult to standardize the tests completely, and when all reasonable steps have been taken,

Government laboratories may not be in a position to publish the results of tests on proprietary products. In the circumstances, strict comparison is impracticable, and selection of a preservative must depend on assessing each particular problem and deciding what are the most important conditions to be satisfied.

THE APPLICATION OF PRESERVATIVES

Having decided on the preservative, the problem of getting it into the wood remains to be settled. The three principal methods are (1) **brush coating**, (2) **dipping**, and (3) **pressure treatments**. But just getting some definite quantity of a preservative into a timber is no guarantee that the treatment will prove satisfactory; depth and uniformity of penetration are of the utmost importance. Uniformity of penetration is dependent largely on the anatomical structure of wood: sapwood absorbs preservatives more readily than heartwood, the early wood of softwoods better than the late wood, and timber of some species more readily than that of others — *e.g.*, Scots pine (European redwood) is much easier to impregnate than Douglas fir, apitong than lauan. The path of penetration of preservatives in hardwoods appears to be different from that in softwoods: in the latter there is appreciable movement through the pits in the cell walls, but in the former movement appears to be largely through the vessels and, in consequence, penetration is very much heavier in hardwoods along than across the grain. Depth of penetration is mainly important when checks are likely to develop after treatment, otherwise in theory the thinnest complete covering is all that is necessary. Wood below a treated skin is very liable to be exposed sooner or later and, when treated green, checks develop and expose wood below the depth of penetration to fungal and insect attack.

Certain general principles should be observed whatever the nature of the preservative or method of treatment. For example, because of its better absorptive powers, sapwood should be retained, and in larger-sized timbers those with a complete outer layer of sapwood should be selected for treatment in preference to those with one or more heartwood faces. Better penetration is obtained with hot than with cold methods of application, and, except with chemicals that decompose on heating, preservatives

should be applied hot whenever practicable. Air-dry timber absorbs preservatives better than green wood, so that timber should be seasoned before treatment; this also ensures that checking will occur before and not after treatment, and the checks themselves facilitate impregnation. All trimming and boring of timber must be done before the wood is treated, or, when this is impossible to arrange, surfaces subsequently exposed should be given a heavy dressing of the preservative; even with such precautions fungi and insects will usually launch their attacks through these weak places.

Brush coating.—Brush coating is the simplest method of applying a preservative, but it is the least efficient. If, however, two or more coats are given, and the treatment is repeated every two or three years, some measure of protection is obtained, particularly with interior wood-work that is not exposed to mechanical wear. The method should, however, only be used when alternative treatments are impracticable, or temporary protection or a short service life alone is required. Wherever practicable, preservatives with good penetrative qualities should be selected.

Spraying and dipping.—Spraying is usually not so effective as brush coating, but dipping is appreciably more effective, because the wood is in contact with an excess of preservative for the duration of the dipping process. If the length of the immersion period is sufficiently long, and the absorptive powers of the wood are good, a considerable quantity of preservative may be taken up in the dipping process, particularly if the preservative is one that can be heated and the bath or dipping tank is filled with hot liquid. When the preservative is applied by spraying there is a risk that the surfaces treated are not thoroughly wetted by the preservative, which may be held by surface tension on rough surfaces or particles of dirt or dust.

Open tank.—A special form of dipping, in effect a modified pressure treatment, known as the **open-tank** method, is much more effective than brush coating or dipping. Except that it is more wasteful of the preservative than certain pressure treatments, the open-tank method gives results comparable with those obtained with pressure processes, provided the timber treated possesses good absorptive properties. The method requires a bath or tank with some form of heating apparatus, in which the timber to be

treated can be completely immersed (Plate 61, fig. 1). The timber is submerged in the cold preservative, which is then gradually heated to a temperature of 160° to 200° F., which is held for ½ hour to 4 hours, after which the preservative is allowed to cool, with the timber still immersed. The peak temperature, and the period that temperature is held, are varied according to the type of preservative and the absorptive powers of the timber. Heating causes the air in the cells of the wood to expand, some being expelled, and, as cooling begins, the air left in the cells contracts, and the external air pressure forces in the preservative to take the place of the air lost. Variation in the length of time the peak treatment-temperature is held, and the peak temperature itself, provide means of governing the degree of heaviness of the treatment and, consequently, the quantity of preservative absorbed by the wood.

The simplest form of open tank is a container that can be heated by external firing, but, because of the risk of the preservative catching fire, steam-heated coils inside the tank are much to be preferred. Various refinements, such as mechanical loading devices and separate cooling tanks, are sometimes introduced, but these are not essential. The method is to be recommended only where the quantity of timber to be treated annually is insufficient to justify the capital outlay on the more expensive, but more efficient, plant necessary for pressure processes.

Pressure processes.—The most effective method of treating timber is the use of a pressure process for forcing the preservative into wood. With such processes penetration is obtained to a considerably greater depth than is possible by any other method. An open-tank treatment is in a sense a pressure process, but the effective pressure employed is of necessity less than one atmosphere. By using closed retorts, on the other hand, high temperatures, and pressures of several atmospheres, can be attained, the only practical limitations being the risk of mechanical damage to the timber. Temperatures in excess of 200° F., or pressures greater than 200 lb. per square inch, are rarely used because of the adverse effect of such temperatures and pressures on woody tissue.

A pressure plant consists of a retort fitted with a door that can be hermetically sealed, a supply of steam for raising temperatures, and hydraulic pressure pumps for controlling the pressure

inside the retort; in commercial-size plants loading is done on trucks outside the retorts (Plate 61, fig. 2).

The oldest pressure process, introduced in 1838, is the **Bethel** process, which is still in use today. In this process the retort is first loaded with timber and then hot preservative is run in and a pressure gradually built up; when it is estimated that an excess of preservative has been injected into the timber the pressure is released and the surplus liquid is drawn off. A common modification of the Bethel process is the application of a vacuum to the timber before running in the preservative. This, it is claimed, by drawing the moisture from the cell cavities, facilitates the subsequent entry of the preservative into the wood; technical opinion does not support this claim, however, holding that the vacuum period generally used in commercial practice is too short to affect the issue. The vacuum, however, serves two purposes: by increasing the effective pressure to which the timber is subjected, there is an increase in the pressure available for forcing the preservative into the wood, and, by establishing a vacuum in the retort, filling is facilitated, particularly if the storage tank is at a lower level than the treating cylinder.

The Bethel process and its modifications are known as full-cell processes; that is, if completely successful, not only is the preservative injected into the cell walls, but the cell cavities also are filled. Except with readily leachable substances, and timbers of low absorptive powers, an excess of preservative occupying the cell cavities is wasteful. To overcome this objection so-called empty-cell processes have been devised. One of these is the **Rueping** process, which involves the use of an initial air pressure, built up in the treating cylinder before the hot preservative is run in. This pressure compresses the air in the cell cavities of the timber. The hot preservative is then introduced and a still higher pressure is built up within the retort until an excess absorption of preservative is secured. The pressure is then reduced to atmospheric pressure, so that the air compressed in the cell cavities of the wood expands and ejects the surplus preservative. In this way a relatively deep impregnation is secured, with a smaller net absorption of preservative, compared with full-cell treatments. A modification of the Rueping process, known as the **Lowry** process, employs an initial, atmospheric-air pressure and a vacuum at the end of the run to extract surplus

preservative; the amount extracted is comparatively small compared with that expelled at the end of the Rueping process.

In another pressure treatment, the Boulton process, an initial vacuum is applied to the timber while it is submerged in the heated preservative. This reduces the boiling point of the water contained in the wood, enabling it to evaporate at a temperature below 212° F. In this way considerable drying of the timber during the treatment can be effected at comparatively low temperatures, and without exposing the wood to the risk of serious degrade.

Incising.—The relative ease with which different timbers absorb preservatives varies appreciably; beech and European redwood sapwood can be completely impregnated under pressure in 1 to 3 hours, but a similar treatment of Douglas fir, larch, or oak heartwood, would not effect complete impregnation in several days. Moreover, a more severe treatment of recalcitrant timbers, using higher temperatures and pressures, does not overcome the difficulty, but merely secures increased absorption in patches. Various attempts have been made to solve the problem of treating such refractory timbers and, of these, an operation known as **incising** has proved the most successful. The process consists in making incisions parallel to the fibres to the depth of penetration required, and spaced sufficiently close together that the lateral spread of the preservative will ensure uniform and complete penetration to the depth of the incisions. By this means an increased absorption of 30 to 60 per cent. has been obtained with Douglas fir sleepers.

Other methods of treatment.—The foregoing pages have outlined the more important methods of applying wood preservatives that are in general use, but one or two other methods are of interest. In the Boucherie process use is made of hydrostatic pressures: a water-soluble preservative is supplied from a raised tank, through a pipe, to the base of a log or baulk of timber fixed in a horizontal position; the hydrostatic head forces the liquid through the timber, the treatment being completed when the preservative appears at the top end of the log. The Boucherie process, with copper sulphate solution as the preservative, is used regularly in France for the treatment of telegraph poles and railway sleepers.

The impregnation of fence posts and telegraph poles *in situ* by diffusion has been tried in Germany. The preservative is injected, in paste form, at several points and spreads by diffusion through the wood: good penetration has been secured by this means with wet timber. The same principle is involved in the attempts to introduce preservatives into timber *before* the tree is felled, but the method is still in an experimental stage.

The impregnation of non-durable timbers with the alcohol extractives (infiltrates) of durable woods has not met with success, although it is known that these substances are responsible for rendering certain timbers naturally durable The reason for this is, no doubt, that the infiltrates or extractives are more intimately associated with the cell-wall structure than can be reproduced by artificial impregnation.

Charring is a well-known method for protecting timber in contact with the ground. No experimental data have been collected to determine the efficacy of the method, but it is unlikely that charring would greatly prolong the life of timber. Charring destroys the accumulated food supplies stored in the parenchymatous tissue of the outer layers of a piece of wood, thereby rendering the charred timber less attractive to insects and fungi. Charring may possibly be justified for small round poles used as temporary fencing, when the cost of a proper preservative treatment cannot be entertained, but it cannot be ranked at all high among the various chemical methods of wood preservation.

ECONOMIC ASPECTS OF WOOD PRESERVATION

Much money is wasted annually through the indiscriminate use of wood preservatives, especially in tropical countries. This waste occurs chiefly through unnecessary application of brush coatings, but inadequate applications may also be wasteful. As a general rule, brush coatings are only justified in circumstances where repeated applications at regular intervals are practicable. Single coatings of inaccessible timbers are either unnecessary, or inadequate. This applies particularly to roof timbers: if conditions are so bad that such timbers require protection, a single brush coating will be insufficient. In practice, roof timbers, except for tile or shingle battens in really damp climates, do

not require any treatment. Battens in damp localities, on the other hand, unless of a naturally durable species, should be pressure treated, or at least given a moderately heavy open-tank treatment. Too frequent recourse to wood preservatives encourages the use of poor quality timber, and even the deliberate substitution of an inferior species to that specified, and for this reason wood preservation by chemical means should only be adopted in circumstances where it can be fully justified.

The economic aspects of wood preservation are more usually confined to weighing the advantages of using a lower-priced, non-durable timber, adequately treated with wood preservatives, against the more expensive timber possessing appreciable natural resistance to fungal and insect attack. In this sense the economic value of a preservative treatment becomes a matter of simple calculation: cost of maintenance and the annual charge on the material treated compared with the same figures for untreated material. The annual charge may be arrived at from the following formula:

$$A = P\frac{r(1+r)^n}{(1+r)^n - 1}.$$

Where A is the annual charge,

P is the cost of material plus erection,

r is the rate of interest, expressed in decimals, *e.g.*, 5 per cent. = 0·05, and

n is the anticipated serviceable life.

Values for n should be based, wherever possible, on figures obtained from service tests.

Other factors that require consideration are the estimated life of a building before it may be presumed to become obsolete, or no longer suitable for the purpose for which it was erected, the salvage value of wood used in a building, and the saving that can be effected through using larger quantities of sapwood. There are undoubtedly many cases where only a short life is required, and in these circumstances it is wasteful to build a structure that will outlast, by many years, that required life.

The value of chemical treatments to enhance other properties than resistance to decay has already been discussed in connection with the hygroscopic properties of wood, *vide* pages 101 and 195. Similarly, improvement of mechanical properties by impregnation

with synthetic resins would appear to have commercial possibilities in special circumstances, *vide* page 101.

The appreciable salvage secured from dismantling wooden buildings is one of the important advantages wood has over alternative building materials, and increasing the life of wood by the use of wood preservatives will enhance its value when the time for dismantling arrives. Increased use of sapwood, permissible as a result of adoption of adequate preservative treatments, may also prove economical, compared with the higher cost of timber free from sapwood.

For timber used in salt water it is known that very heavy absorptions are required to secure even moderate extensions of serviceable life, and in such cases the use of chemical wood preservatives is rarely economical, compared with sheathing of wood with thin metal sheets. For piles in salt water, absorptions up to 15 lb. per cu. ft have been used to secure a serviceable life of well under ten years. In such circumstances it would undoubtedly have been more economical to use comparatively light treatments, and to sheath the piles with Muntz metal. The object of the light treatment is to secure some resistance should the sheathing become damaged in the interval between regular inspections, which should be made three or four times each year. Evidence from Malaya is to the effect that such sheathed piles have a very long life, although the timber has only moderate resistance to marine borers: sheathed merbau piles were still perfectly sound after 27 years' service. Unprotected greenheart would certainly not have lasted nearly so long in the particular circumstances.

Another aspect of the economics of wood preservation, outside the control of the individual user, is of the utmost importance to him. If the use of wood preservatives permits of the utilization of many species that would otherwise be valueless, exploitation of the forests as a whole will be less costly. Further, the availability of adequate timber supplies will tend to keep prices of the most favoured species at a steadier level. Both these factors apply particularly in the tropics, where the number of species in any unit area of forest is large, and the number commercially exploitable without the use of wood preservatives is very small.

CHAPTER XV

THE ERADICATION OF FUNGAL AND INSECT ATTACK

Timber used as railway sleepers, fence posts, power-line poles, and the like is inevitably exposed to conditions favouring attack throughout its service life. By contrast, certain conditions of service ensure that timber never becomes attacked: piling timbers in deep water or timber in the abnormally dry atmosphere of the Egyptian tombs will remain free from attack indefinitely. Much more timber is used in circumstances between these extremes of certain attack and complete immunity, giving rise to the need for prophylactic measures or problems of eradication.

Timbers predisposed to attack by sap-stain fungi, "pin-hole" borers, or "powder-post" beetles are very liable to suffer deterioration unless appropriate precautions or prophylactic measures are taken. The sapwood of those timbers susceptible to "mould" fungi are liable to become stained unless logs are converted immediately after felling, and the converted material is then dried so rapidly that the fungal "spores" are not given the opportunity to germinate. It is often not possible to arrange for sufficiently rapid drying, in which case the use of chemical dips provides a practicable solution. The sodium salts of certain chlorinated phenols are particularly effective against both the blue-stain fungi and other moulds. Examples of highly successful proprietary products using this group of chemicals are Dowicide P,[1] and Santobrite.[2] Certain organic mercurial salts have been found very effective in controlling blue-stain, but less so against green moulds: Lignasan[3] contains ethyl mercuric chloride as the toxic agent. Two per cent. solutions of borax have also given good protection against blue-stain fungi. These chemicals, used in a dipping bath or trough through which the timber passes as it comes off the saw, provide

[1] Manufactured by Chemical Treatments Co., 1604 Per Marquette, New Orleans, Louisiana.

[2] Manufactured by Monsanto Chemicals Ltd., Victoria Street, London, S.W.1.

[3] Marketed by E. I. du Pont de Nemours & Co., Wilmington, Delaware.

a practicable solution of the blue-stain problem. The period of immersion is brief: 20 seconds is usually quite sufficient. After dipping, the timber must be given a chance to drain before it is piled in a stack. With some of the tropical timbers, where blue-stain infection is not confined to the sapwood, prevention of stain in planks 3 in. in thickness and upwards has often not been secured by chemical dips alone. Great care has to be taken to drain the planks before piling, often necessitating exposure to the sun, with frequent turning to obviate surface checking. Besides the handling cost involved, the yard space is rapidly taxed to capacity with planks draining and drying preparatory to piling. The most satisfactory procedure with such timbers is kiln drying, but these facilities are often not available, when the alternative is to cut as thin timber as possible: 1 in. or 1½ in. boards can usually be air-dried, after dipping, without staining.

"Pin-hole" borers present a somewhat similar problem to that of sap-stain fungi, in that attack is dependent on the existence of sufficient moisture in the wood to support the growth of the ambrosia fungus on which the pin-hole borer larvae feed. Some species attack standing trees, so that the damage is done before the trees are felled, and no methods have as yet been devised for dealing with infestation in this stage. Much infestation, however, undoubtedly occurs after felling, while logs are lying in the forest or at the mill awaiting conversion. Extraction immediately after felling, followed by immediate conversion at the mill, and proper piling to ensure rapid drying of the converted timber, would unquestionably minimize the wide-spread damage done by pin-hole borers. The rapidity with which these borers attack the logs of some species, coupled with the difficulties of organizing extraction and conversion, makes dependence on rapid extraction and conversion to avoid infestation uncertain, and chemical sprays have been used with some success. Disappointing results were obtained with chemicals that have proved effective against sap-stain fungi, and creosote and certain proprietary tar-oil preservatives proved a positive attraction to some ambrosia beetles. The gamma isomer of benzine hexachloride, available as a powder miscible with water or as a dispersion in oil, on the other hand, has given encouraging results. The water-miscible powder appears to give surprisingly good protection at considerably lower gamma isomer concentrations than the oil dis-

persions, but it is easily washed off by rain;[1] it has the advantage of being much less expensive than the oil dispersions. Although chemical prophylactic measures are still very much in the experimental stage, there is little doubt that effective treatments against much pin-hole borer infestation can be devised. It is, however, doubtful whether the general use of chemicals will prove practicable: where it is essential to apply the treatments in the forest, the difficulties of organizing supplies of the preservative, and the supervision of their application, may prove unsurmountable. Where a short delay between felling and the prophylactic treatment is unimportant, it should be possible to organize the application of an effective short-term treatment at log-collecting depôts — these are matters that remain to be investigated thoroughly. From somewhat tentative investigations, it would seem that some timbers are attacked by some species of pin-hole borers within a matter of a few hours of felling, whereas, with other timbers and other borers, a few days may elapse before extensive attack occurs.

The countering of "powder-post" beetle attack presents a problem intermediate in complexity between elimination of sap-stain fungal infection and "pin-hole" borer attack on the one hand, and eradication of fungal or insect attack in timber in service. Attack does not normally occur in the log, but *Bostrychid* beetles will attack timber very soon after conversion, and *Lyctus* as the timber becomes drier. Good yard hygiene, on the lines discussed on page 228, can play a very important part in minimizing the depredations of this pest, but, until good practice is general throughout the country, resort to chemical dips or spraying is often advisable. Successful 10-second dips are 5 per cent. borax at a temperature of 180° F., and 1 or 2 per cent. aqueous solutions of "sulfocide" (sodium pentasulphide in liquid form) at 190° F. Solvent-type preservatives have also been tried on seasoned timber: a 3 per cent. solution of pentachlorophenol, in a light fuel oil of the kerosene range, and an immersion period of 3 minutes, has given good results. In this country, the available evidence points to the need for purely transitory protection against *Lyctus* (apart from eradication of outbreaks when these occur): were joinery, furniture, etc., delivered free from infestation, the likelihood of attack occurring in service would be remote. This, of course, presupposes that manufactured articles will not be stored

[1] Browne, F. G., *The Malayan Forester*, No. 4, 1949.

in already contaminated premises. In effect, precautions are especially necessary while timber is in stick for drying, or awaiting manufacture. For these circumstances, it has been found that a 2 per cent. emulsion of D.D.T. in water, applied by spraying to piled timber, is effective; complete coverage of the sapwood must be secured. The spray is prepared from miscible oil concentrates in solvent naphtha or xylene containing some specified amount of D.D.T. diluted with water to the D.D.T. concentration required. No penetration of the timber is aimed at, or secured, with this spray, so that when timber is worked or re-sawn it will require spraying anew if it is likely to be exposed to infestation before being made up.

The question is often posed as to whether decay and "woodworm" infestation in buildings is more prevalent today than formerly, and the answer is undoubtedly in the affirmative. The increased incidence of "decay" is attributable to rather different causes from those responsible for more widespread depredations of insect pests. Formerly, many outbreaks of fungal infection could be directly related to constructional defects, although many buildings that fell short of good standards of construction managed to escape attack. The war years and economic factors have materially changed the position. Delays in making good war damage, and the large quantities of water used in putting out fires, have caused well-constructed buildings to become the victims of widespread fungal attack; in buildings that fall short of good construction, the consequences were naturally the more serious and inevitable. Further, normal maintenance was in abeyance for six or seven years, and properties were often uninhabited for long periods, so that any small defects that developed tended to assume considerable importance. Fuel rationing, the shortage of domestic staff, and financial stringencies — factors likely to persist — have operated similarly, especially in larger houses: with only some accommodation in regular use, the woodwork of unheated and unventilated rooms will pick up moisture wherever defects in construction exist, ultimately creating conditions favourable to fungal growth. That the whole of such accommodation was formerly used, well heated and adequately ventilated, enabled border-line cases of bad construction to escape penalties.

Availability of moisture is, in practice, the factor that governs liability to fungal infection, although different fungi vary in regard

to their "total" moisture requirements. With insect pests, favourable factors are more varied: the death-watch beetle, the wood-boring weevil, and the wharf borer thrive only on timber that has first been attacked by fungi, although the death-watch beetle will spread to sound wood. The common furniture beetle is less exacting, but shows a preference for sapwood. The *Lyctus*, or powder-post beetle, is the most exacting of all, confining itself to the sapwood of certain hardwoods, and then only if adequate supplies of starch are present and the timber is sufficiently seasoned.

ERADICATION OF FUNGAL DECAY

Recommendations for dealing with "dry rot" are to be found in the Bible (Leviticus xiv. 34-48). The fungal origin of the "plague" or "leprosy" was not known until centuries later, but the passage is of interest in that it brings out two important points: the need for establishing that attack is still active, and the need for drastic remedial measures — rather too drastic in the light of modern knowledge. The fungus would not have been *Merulius lacrymans* as the temperatures in Palestine are too high for this species. The Old Testament writer overlooked an all-important point: namely, the importance of tracing the source of moisture that gave rise to fungal infection in the first place. By comparison, it is less important to identify the species of fungus, although it is, of course, essential to determine whether *Merulius lacrymans* is involved, since this fungus calls for altogether more drastic remedial measures than any other.

The three most common faults, when dealing with outbreaks of fungal attack, are to do too little "site" investigation, to do too extensive replacements, and to ignore the fundamental cause, namely a supply of moisture. It is essential to determine the full extent of infection, but knowing what to look for, and where to look for it, will minimize the amount of opening up to be done. Time spent on the careful examination of the exterior of a building is usually well repaid. The more obvious points in regard to damp-proof courses, and levels of flower-beds and paths, are generally understood. The importance of an adequate number of air bricks is also fully appreciated, although it is sometimes overlooked that their number may be adequate and yet the air bricks are ineffective: they may be obscured by a plate or joists

on the inside. Many air bricks have, at best, only 50 per cent. of voids, and a floor joist or plate can reduce this 50 per cent. to almost nothing. Water from above — from defective gutters, rainwater heads, or down pipes — can cause as widespread devastation as indifferent ventilation below the ground floor. Hence, the condition of the rainwater disposal arrangements, and their efficacy, warrant close examination: staining of external walls, the growth of algae, and the condition of pointing — or evidence that such matters have recently received attention — will often indicate where the search for fungal infection should be directed inside the building. Parapet gutters, "internal" valley gutters, and lead or asphalt "flats" are other fruitful sources of trouble, and any defects in these features, or signs of past patching, call for particular attention being given to the condition of timber beneath such weak spots. Past history can be most relevant: flooding from burst pipes, when the property is unoccupied, or water used in putting out fires, can cause the most extensive dry-rot. Areas of new slates or tiles should arouse suspicion. Armed with clues on the lines discussed above, tracing of infection is simplified. Corrugations in skirtings and panelling are obvious defects to look for, but even bowing of such timbers, if on the opposite side of a wall where "defects" exist outside, should not be given the benefit of any doubt: removal of such timber often reveals surprisingly extensive, "unsuspected" decay.

Having located infection, and its extent, it is essential to determine where the wood obtained a supply of moisture sufficient to render it fit to support fungal growth. Very often an outbreak has more than one "focal" point, which means more than one source of moisture, and it is all-important that this should be detected. Moisture will not travel upwards nearly so far as it will travel downwards: infection in basement or ground-floor rooms will be sustained by a different source of moisture from infection in the same premises but on the first or higher floors.

Until the source of moisture is traced, the appropriate remedial measures cannot be laid down. For example, moisture arising from constructional defects can only be eliminated if these defects are corrected, or, when this is impracticable or too costly, by recognizing that no timber should be used in repairs that will not be isolated from the source of moisture by a water-impervious barrier.

The badly ventilated basement floor, with no site concrete and no damp-proof courses in the walls, presents just the problem envisaged. However thoroughly the wood is stripped out and replaced by new, fungal infection will reappear *unless* moisture can be excluded from the underfloor space, and good ventilation be provided ; heat sterilization of the surrounding surfaces is purely transitory, and the liberal use of wood preservatives will, at best, defer the date of reinfection. In practice, it will generally prove too costly to remedy major constructional defects, and the solution will lie in using inorganic materials in repairs. Affected basement floors should be replaced with solid floors, with wood blocks, laid in a bituminous mastic, as the finished surface.

When the floor area is large, as in a gymnasium or concert hall, decay has been known to occur, in spite of the existence of damp-proof courses in all walls, and provision of the normal number of air bricks. For example, 1½ sq. in. of air bricks per foot run of wall does not ensure a constant area of air bricks per unit volume of underfloor air space — the ratio falls as the area enclosed by the external walls increases.[1] In a building 30 ft by 15 ft, with 1½ sq. in. of air brick per foot run of wall, and 1 ft between site concrete and the under surface of the floor boards, 135 sq. in. of air bricks are dealing with 450 cu. ft. of air, whereas for a building 150 ft by 30 ft, and the same ratio of air bricks per unit length of wall, 540 sq. in. of air bricks would have to deal with 4500 cu. ft of air. In effect, it is sometimes impossible to ventilate the underfloor space of large areas adequately, and moisture must be excluded by providing a waterproof barrier in the site concrete.

Decay resulting from what can be regarded as temporary sources of moisture presents an entirely different problem from that arising from what may be called chronic dampness, and the appropriate remedial measures should be dependent on the identity of the fungus. Defective rainwater disposal arrangements, the raising of flower-beds above damp-proof courses, the blocking of air bricks, and the temporary flooding of normally dry sites (as in combating a fire) are the chain of circumstances most likely to establish conditions favourable to " dry rot " infection, and, in particular, to *Merulius lacrymans*. Persistent plumbing leaks, defective flashings, and recurring condensation, on the other hand, are

[1] I am indebted to Dr. W. P. K. Findlay for drawing my attention to this point.

more likely to make timber too wet for *Merulius*, and one of the so-called "wet rots" is more likely to develop. Cure of the cause of dampness in the examples enumerated presents no great difficulty, and such action alone will, in many cases, arrest further decay. It is, of course, necessary to cut back affected wood to sound material, and to use well-seasoned timber in repairs; if there is a risk of dampness recurring from neglect of maintenance in the future, the use of pressure-treated timber in repairs should be considered. Timber that has been exposed to attack, and is only very slightly decayed, can be rendered safe by a brief kiln-sterilizing treatment; application of preservatives to such wood is unlikely to kill all traces of fungus. When panelling or valuable flooring has become sufficiently damp to support fungal growth, it is usually advisable to dismantle such timber and to dry it, otherwise splits may develop as the timber dries *in situ*, or, with floors, compression set may have been induced (see page 94).

Where *Merulius lacrymans*, the common "dry rot" fungus, is the causal agent, more drastic measures than those outlined above are likely to be essential. This fungus penetrates masonry and brickwork, where it can remain dormant for long periods, if its minimum moisture needs can be satisfied. In practice, walls that have become saturated are likely to retain sufficient moisture to sustain *Merulius* for some years after the original source of water has been cut off, which explains the recurring attacks so frequently experienced after an outbreak of *Merulius lacrymans* infestation: as soon as the new timber has had time to absorb sufficient moisture from the wall to raise its moisture content to about 20 per cent., conditions are ripe for the fungus to resume active growth on the new timber provided. The common precautionary measure of heat sterilization of walls with a blow-lamp is totally inadequate: raising the temperature of one face of a 4½ in. brick wall to 900° C., and holding that temperature for four hours, will only raise the temperature of the opposite face to about 50° C. The surface application of chemicals is unlikely to be any more effective, and elaborate irrigating of walls is costly in labour, and in the large quantities of chemicals absorbed, besides being somewhat uncertain. The scientists of the Forest Products Research Laboratory, Princes Risborough, in collaboration with those at the Building Research Station, Watford, have evolved a toxic plaster and paint that promises to provide a

measure of security at reasonable cost.[1] No attempt is made to destroy deep-seated fungus in the affected wall; instead, a non-crazing barrier is erected, which the fungus will not cross. The basis of this method is zinc oxide, gauged with a solution of zinc chloride. The other ingredients of the plaster are sand and whiting, and of the "paint" talc and whiting. Boric acid and ammonium chloride are added to the zinc-chloride solution to act as retarders. The solid ingredients of the plaster are gauged with the solution, and applied to the wall in the same manner as any other plaster, any gypsum plaster must first be removed. The surface to be treated may require to be hacked to provide a key. Surfaces so rendered can be decorated when dry in the normal way, or, if an adequate key is provided, a setting coat of a calcium sulphate plaster can be applied. The ingredients are relatively expensive, but only a thin coat is required. Where it is necessary to build timbers into affected walls, the wall holds should be rendered with the plaster. The paint is made up in the same way as any cement paint; that is, the solid ingredients are first

[1] The formulae for the plaster, paint, and solution, as recommended by the Government chemists, are set out below. Important points are the use of an appropriate grade of zinc oxide and dry sand, otherwise the proportions are not "critical" in the sense that small errors in weighing, such as may occur in ordinary practice, are unimportant. Rather more solution than is required for gauging the plaster or paint is necessary, as surfaces to be treated should be wetted with the solution before the plaster or paint is applied. In gauging the plaster, care should be exercised in adding the solution as the correct consistency for applying the plaster is approached, because a small amount of fluid at that stage has a marked effect on the consistency of the mix. It is important to cut out all timber in walls to be plastered or painted. Experience has shown that it is essential to mix the solids and the solution off the site, because otherwise there are never enough clean containers to hand when required, gauging is, of course, done on the site just prior to use. Messrs. J. W. Falkner & Son, Ltd., of 24 Ossory Road, London, S.E. 1, maintain a stock of ready mixed ingredients.

Gauging Solution for Paint and Plaster	*Parts by Weight*
Fused zinc chloride (technical)	8
Boric acid	1
Ammonium chloride	1
Water	20

Solid Ingredients

Paint		*Plaster*	
Zinc oxide (B.S. 254 Type 1)	2	Zinc oxide (B.S. 254 Type 1)	1
Talc	4	25/50 mesh sand	5
Whiting	6	52/100 mesh sand	2
		Whiting	1

Approximately 9 parts by weight of mix to 2 parts by weight of solution is suggested.

mixed, and gauged immediately before use with the solution, the ratio being 12 parts by weight of solids to 9 parts by weight of the solution; two coats are recommended, with an interval of twenty-four hours between each coat. The use of zinc oxichloride paint or plaster does not do away with the need for eliminating the source of moisture in future.

To sum up: control and eradication of fungal infection in buildings is first and foremost dependent on tracing and eliminating the source of moisture. Subsequent steps depend on whether the fungus is *Merulius lacrymans* or one or other of the less virulent fungi. Toxic chemicals may have a part to play, but only in a secondary rôle. The work of eradication is likely to necessitate the assistance of carpenters, bricklayers, and plasterers, often the plumber and tiler as well, and is, therefore, essentially a job for the building contractor, fully aware of the importance of each step. Thoroughness is the keystone of success.

ERADICATION OF INSECT INFESTATION

In temperate climates insect infestation of timber on land means beetle attack; in salt or brackish water, marine borers are the destructive agent. Control and eradication of beetle infestation are dependent on an understanding of the life cycle of different species and their food requirements. The life cycle of any species is liable to be prolonged if its preferred food supply is deficient. In dealing with insect attack it is all-important to determine which pest is at work before attempting eradication: drawing-pin holes from the blackout days have been mistaken for beetle infestation. The use of wood preservatives, applied *in situ*, will often prove the only practicable method for dealing with insect infestation, when brushing the timber free from dirt is an essential preliminary, to secure thorough "wetting" of the wood.

If the damage is the work of the "pin-hole" borer (ambrosia beetle), no remedial measures are necessary: such "wormy" timber is perfectly safe to use, since the damage will not get worse, and cannot infect other wood. These pests are mainly tropical, hence infestation and the full extent of the damage done occur before such timbers are exported. Control of pin-hole borer infestation rests with those exploiting tropical forests, and the appropriate measures are discussed on pages 263 and 264. "Pin-

worm " infestation can usually be differentiated from other forms of insect attack by the galleries running at right angles to the grain; the galleries of different species vary from $\frac{1}{50}$ to $\frac{1}{8}$ in. in diameter.

Longhorn borers are also mainly forest pests, although one species, the house longhorn (*Hylotrupes bajulus*), attacks converted softwoods. With the exception of the last-mentioned species, attack is best dealt with in the forest: logs must not be left lying on the ground, and if extraction is likely to be delayed, logs should be barked immediately after felling. The house longhorn is a serious pest in parts of Sweden, Denmark, and Germany, and has caused damage in the pine country of Surrey. It attacks the sapwood of seasoned softwoods (the heartwood is not completely immune). Extensive damage is likely to have occurred before the first flight holes are detected, because the life cycle is relatively long (3 to 11 years), and indications of attack, other than flight holes, are often wanting, or are easily overlooked (*e.g.* blister-like swellings on the surface of infested wood). Attack generally originates in the roof timbers and attics, from which it may spread to other timbers throughout the building. Remedial measures are likely to involve replacing appreciable quantities of timber, coupled with application *in situ* of wood preservatives. Heat sterilization and fumigation are used on the continent in combating outbreaks, but facilities for heat sterilization are not available in this country, and fumigation is impracticable in most houses, particularly in built-up areas. The use of wood preservatives calls for very thorough applications to ensure that all timber surfaces are adequately treated: surface applications secure only very shallow penetration of wood by the fluid used. Inspection, for signs of renewed infestation in ensuing years, is advisable. Oil-solvent wood preservatives are appropriate: a 5 per cent. solution of pentachlorophenol and 0·35 per cent. of gamma B.H.C. in a suitable oil or spirit solvent is an economical preservative that can be made up in quantity at much less cost than most proprietary products. Where the pest is prevalent it is wise to use only pressure-treated timber in repairs and for all new work; brush-treatments give only short-term protection.

The death-watch beetle is almost always associated with decay, although, once established, the beetle may extend its attack to sound wood. Hence, in dealing with death-watch beetle infestation, it is imperative to deal with the decay too,

since the cause of this will have been responsible for the subsequent, and "secondary", beetle infestation. It is also important to decide whether the beetle infestation is still active: "It is a common feature of damage by the death watch beetle for attack to cease before all the available timber has been destroyed, and this is no doubt due to absence of the conditions of moisture and fungal decay now known to be suitable for attack and which must once have been present in the building".[1] It is not always easy to determine whether attack is continuing, although clear-cut rims to the flight holes, from which bright-coloured frass is spilling out, indicate the recent emergence of adult beetles. A search of the ground beneath attacked timber during the emergence period (April to June) is helpful: live beetles will usually be found if attack is still active. The presence of large numbers of live, steely blue beetles (*Corycorinetes coeruleus*), predatory on the death-watch beetle, also provides evidence of continuing attack. If investigation shows that attack has ceased, the lavish use of wood preservatives is obviously unnecessary. In many cases of continuing attack, too, cutting off supplies of moisture, which will bring decay to an end, may be as effective as attempting to eliminate the beetle infestation. In dealing with serious devastation the first step is to conduct a thorough check for any signs of decay, the cause of which must be eliminated; next, replacement of all structurally weakened timber; and, finally, treatment *in situ*, with an oil-solvent preservative, of timber that has been exposed to infestation, to destroy any remaining infestation; surface applications should be supplemented by injecting flight holes with a pressure spray. Eradication is likely to necessitate "repeat" treatments in succeeding years, but these can be confined to areas of continuing active infestation, provided thorough inspections will be made in May each year.

Two other beetles infest decayed building timbers: the common wood-boring weevil, often found in basement floors, and the much larger wharf borer. Both these pests are secondary to fungal decay, and their control by chemical means (wood preservatives) should not be attempted. Exclusion of the source of moisture, coupled with the cutting out of decayed and infested wood, may well suffice. Damage done by the wood-boring

[1] Leaflet No. 4: *The death watch beetle*, issued by the Department of Scientific and Industrial Research, Forest Products Research Laboratory.

weevil is sometimes mistaken for furniture-beetle attack: the galleries run longitudinally, and are of about the same diameter, and the frass excreted by the feeding larvae is gritty but finer.

The common furniture beetle is a pest of sound, seasoned timber, but with preference for sapwood. Softwoods appear to be ripe for attack after they have been in service for about 15 years, whereas hardwoods are rarely attacked within the first 20 to 30 years. The larvae excrete a gritty frass, which contains elongate pellets. In dealing with outbreaks, it is important to determine whether the infestation is still active, because only then are remedial measures necessary: inspections should be made in the early months of the "flight" season, *i.e.*, April to June. With experience, fresh infestation can be detected by the bright colour of the frass, which appears to be spilling out of the flight holes, and the margins of the holes are clear-cut. With age the frass becomes discoloured, and the rims of the flight holes burred over. Two distinct tasks are involved when dealing with active infestation: eradication of existing infestation and protective measures against reinfestation. Wherever practicable, heat sterilization is the most effective method to employ (see pages 251-2 for recommended schedules). Obviously, only movable timber can be so treated, *e.g.*, panelling, flooring, furniture, and small wooden articles. Sterilization calls for only low temperatures, at moderately high humidities, for relatively short periods, which should not damage glue joints or polish finishes. The treatment is done in an ordinary timber-drying kiln, which must, however, be in charge of a skilled operative. Were it possible to ensure that all infested timber in a building was sterilized, there would be no need for subsequent protective measures. This, however, is rarely practicable, and sterilization needs to be supplemented by treating all surfaces with the pentachlorophenol gamma B.H.C. preservative previously mentioned or some other oil-solvent preservative. For application to other than structural timbers, the solvent should be white spirit or odourless paraffin. A small-scale test should be made before applying the preservative to polished surfaces. After sterilization, there is little point in treating polished surfaces, unless these are riddled with flight holes, because eggs are not laid on such surfaces. Before refixing panelling or skirtings, the grounds should be examined: they are almost certain to be attacked, and replace-

ment with pressure-treated timber (Tanalized or Celcure treatments are appropriate) is sound practice. Next to heat sterilization, fumigation is likely to prove the most effective control method. This work must be done by specialist firms; methyl bromide is an appropriate fumigant. In practice, many outbreaks of furniture-beetle attack will have to be dealt with by *in situ* treatments. Timber should be brushed down prior to treatment, or a powerful vacuum cleaner can be used; any heavily infested timber should be cut away. The preservative should be applied with a flat brush in two coats, with at least twenty-four hours between each coat. Inaccessible timber should be sprayed, using a small pressure spray. Where infestation is heavy, one or two flight holes in each group should be injected. The preservative should not be allowed to run down on to plaster surfaces. In theory, all timber that has been exposed to infestation should be treated, but this is rarely economically practicable. There is likely to be much hidden timber requiring treatment, *e.g.*, joists and plates, roof timbers behind sloping plastered ceilings. Some opening up is essential to determine the severity of attack in such timbers. If these are not structurally weakened, the use of smoke generators [1] provide an economical method of eradicating attack in confined spaces, *e.g.*, roof voids. Holes require to be cut in plastered ceilings, or occasional floor boards taken up, to permit of inserting ignited generators, but this involves much less making good than would be involved were it necessary to take up floors or hack down ceilings. The "smoke" given off by these generators is only effective against emerging adults; no penetration of the wood is secured. The generators should be used about once each month during the "flight" season of the pest. Provided thorough inspections are made regularly each year, treatment can be confined to actually attacked timber, and immediately adjacent members; it is advisable to take up flooring to permit of treating joists and plates beneath.

The *Lyctus* beetle is the common powder-post beetle, the larvae of which feed on the starch stored in the sapwood of some timbers. Only hardwoods are attacked, and then only species of timber with pores large enough for egg-laying (about $\frac{1}{16}$ mm.

[1] Messrs. Wasco Limited, High Post, Salisbury, Wilts., and Imperial Chemical Industries manufacture smoke generators.

in diameter): seasoned, or nearly fully seasoned, timber is selected by the adult for egg-laying. In effect, only some timbers are attacked, and then only the sapwood of such timbers, provided it contains sufficient stored starch. The frass is a very fine powder, which feels like flour when rubbed between the fingers.

Eradication of powder-post beetle infestation is rather more difficult than dealing with furniture-beetle attack, because the damage is usually more deep-seated and extensive by the time it is detected. Where practicable, heat-sterilization is the most effective method of eradication, and, provided no timber is excluded from sterilization, further precautions are likely to be unnecessary. Heat-sterilization is, however, often impracticable, and the infestation has to be dealt with on the site. If the attack is at all widespread, it will often prove more economical in the long run to deal with it by cutting out the sapwood of all susceptible timbers. If less drastic measures are decided upon, obviously attacked material should be cut out, and any sapwood retained should be treated with an oil-solvent preservative.

To sum up: identification of the particular pest at work is important, but it is of no less importance to establish whether or not there is continuing, *active* infestation. Thousands of pounds are being expended annually in applying wood preservatives indiscriminately to the timbers of our churches and other buildings, often when infestation is no longer active, and even may have been "dead" for upwards of a century or more. With some insects, it is often sufficient to concentrate on eradicating decay, which will dispose of the beetle pests too. Heat-sterilization is the most certain method of killing all stages of infestation, and is recommended in all appropriate circumstances. The *in situ* use of wood preservatives has an important place in dealing with areas of continuing, active infestation, and where it is essential to prevent re-infestation. It must not be overlooked that preservatives do not restore the strength properties of attacked timbers, and a single treatment is unlikely to secure 100 per cent. success. The proper cleaning of wood prior to treatment, and the thoroughness with which the preservative is applied, are all-important. The initial cost of a preservative is not a good yardstick for assessing its efficacy; a disclosed formula, whose proper cost can be accurately determined, is to be preferred.

CHAPTER XVI

GRADING OF TIMBER

GENERAL PRINCIPLES

The inherent variability of natural products presents many difficulties in their marketing, particularly since competition and mass production have brought a high degree of uniformity in rival, manufactured materials. Timber producers have long found it advantageous to study the variability of wood, and some have evolved sets of rules and grading marks that have come to be regarded as a guarantee of high quality. Unfortunately in some countries there is little standardization in the quality of timber from different mills, and some producers are found to be inconsistent in their grading over a period of years. In the interests of all parties, attempts have been made on the part of various Governments to standardize the grading of many natural products, but timber has generally escaped such beneficial action, and in this country there has been no concerted effort on the part of the industry as a whole to introduce grading rules.

A set of rules applicable to organic materials must of necessity be to some extent arbitrary, and the rules will invariably be subject to the personal factor in interpretation. This accounts in part for the delay in the universal acceptance of grading rules for timber. The first set of rules was issued as long ago as 1764, when Sven Alversdon of Stockholm defined four grades of Swedish pine, *i.e.*, " best ", " good ", " common ", and " culls ", and there have been the Hernosand rules since 1880, but timber has not been obtainable graded in accordance with these written rules.

rules in the United Kingdom, although for large contracts it would probably be obtainable if so specified.

In America and Canada timber has been graded for many years in accordance with special, written grading rules, agreed on by the different sections of the industry as a whole. These rules have the great advantage of having been drawn up by those thoroughly acquainted with the quality of timber ordinarily produced in the mills of each particular region, and the rules are revised and modified to meet changing market needs. In consequence, the rules meet consumers' requirements, but remain essentially workable. This is an important point, and one that is noticeably absent in rules drawn up by consumers, say, in London, for use in Africa or Asia. However desirable it may be that timbers should be of some particular quality, only a small proportion of the outturn of a region will be found to conform with a set of arbitrary rules that have not taken into account the range in quality ordinarily encountered in the mill. With data on the last-mentioned point, the problem of drawing up a set of rules becomes practicable, standards can be devised that fit the outturn, while meeting the essential requirements of the consumer. The alternative, of drawing up rules to meet consumers' demands, is usually unsatisfactory: much timber just fails to come up to the standard of each particular grade and has to be degraded to the next lower grade; slight modifications in the rules, shifting the emphasis on certain grading criteria, would often make such degrading unnecessary, and yet would ensure retention of emphasis on qualities of most importance to consumers. Rules drawn up by producers must, however, take sufficient regard of market requirements, otherwise purchasers will have no confidence in the products offered.

North American published rules are lengthy documents that cover every aspect of sorting the mixed outturn of sawn timber obtained by breaking down logs in a saw-mill. Personal judgement still comes in, but it is specifically laid down that such judgement must not supersede stated conditions in the rules themselves. It has been found that whereas two experienced graders may differ somewhat as to the grade of individual pieces of timber, when whole consignments are judged, such individual differences are evened out. The aim is to achieve standardization in quality, and this will more readily result from intelligent interpretation of the

rules than rigid adherence to the letter — hence the importance of skilled judgement in graders.

Grading is done from the worst face of every piece of timber, unless otherwise specified. It is usual to allow a small margin, say, 5 per cent., of below-grade material to cover the human factor in grading. Lengths, widths, and thicknesses are standardized, with maximum allowances laid down for variations from these standards. Standard lengths are usually even numbers for softwoods, with 9, 11, 13, and 15 feet lengths in certain thicknesses, and both odd and even feet from 4 to 16 feet for hardwoods, with not over 50 per cent. of odd lengths. Standard thicknesses and standard widths are similarly prescribed in the rules, but in these two dimensions the sizes are nominal; that is, the actual widths and thicknesses are less, within specified limits, than the named dimensions.

Many grades are determined on a defect basis; that is, the different defects are given a numerical value, and, according to the grade, different maximum scores are allowed, depending on the size of the piece. In the National Hardwood Lumber Association's rules a knot 1¼ in. in diameter constitutes a standard defect, four pin-worm holes or their equivalent also constitute one standard defect; knots 2½ in. in diameter count as two standard defects, and so on. Alternatively, the grade is fixed by the percentage of clear timber obtained by cross-cutting or ripping, or both, to exclude defects; the percentage of clear timber so obtained, the number of separate cuttings to obtain such timber, and the minimum sizes of pieces to count as cuttings, vary in the different grades. There are many grades, *e.g.*, First, Seconds Select, No. 1 Common, No. 2 Common; firsts and seconds are frequently combined as one grade with a minimum percentage of firsts to be included.

To ensure uniformity of grading as far as possible, several of the larger lumber associations in North America employ corps of men who grade the produce of all the members. In this way grading is made entirely independent of the millers, and the public is assured of a minimum standard, wherever the purchase is made. This has been tested by observers from the Forest Products Laboratory, Madison, by surveys carried out in many States. There is still adequate scope for individuality, by attention to detail not specifically covered by grading rules.

THE BALTIC TRADE

Before discussing the standardized rules in use it will be as well to consider the position in those countries that have not adopted standard rules. Chief of these, as far as the British market is concerned, are the Baltic countries, including Russia, which supplied the bulk of the carcassing timber used in the United Kingdom up to the time of the Ottawa Conference in 1933, and these countries still supply the greater proportion of our needs. Grading in these countries is in essentially the same state as it was forty or more years ago, with the important difference that there has been a marked falling-off in quality of timber exported. The only possible exception to this statement is Finland since 1937: whereas the Hernosand rules applied to one district of Sweden, the Forest Products Association of Finland sponsored a committee to draw up grading rules for that country as a whole. A set of rules was published in 1936–7, but how much timber graded in accordance with the rules reached the United Kingdom is not known. It is, therefore, generally true to assert that every manufacturer follows his own rules, the actual grading, or bracking as it is called, being done by men with a lifelong association with timber. The grades used are 1sts, 2nds, 3rds, 4ths, 5ths, and 6ths, and "unsorted", the last being a mixture of grades better than 5ths. The bulk of the timber from the Scandinavian countries is graded as "unsorted" or 5ths, and that from Russia as 1sts, 2nds, or 3rds. In the Scandinavian countries heavy cutting in the past has necessitated the opening-up of new areas of forest, with the result that the nature of the raw material coming to the mills has changed. Shippers who have been in the habit of obtaining supplies from one locality year after year are obliged to go to different localities each year, and the brackers, with only empirical experience to guide them, are dependent on their own judgement for maintaining continuity of quality. Moreover, when it has been customary for the total production to yield certain percentages of each quality for many years, there is a tendency to secure the same percentages, irrespective of any fall in quality in the mill intake. Nowadays the produce of successive years, shipped under the same marks, may vary appreciably and, in consequence, the purchaser can no longer depend on particular shipping marks to secure the type of timber required.

The practice of architects, surveyors, and engineers, of specifying their requirements in considerable detail, does little to alleviate the position. Until quite recently, the specifications frequently imposed ridiculous limitations. For example, the contractor was frequently called on to supply timber "straight in the grain, free of sapwood, knots, and other defects", and clauses were sometimes added to exclude "dead" wood and "blue-stain". Such specifications are, and always have been, impossible of fulfilment. Timber is a natural product and is never absolutely free from defects or minor blemishes, many of which impair its utility but little. Some latitude, for example, in straightness of grain is permissible for most purposes, the exclusion of sapwood is rarely essential and is frequently impossible, and knots cannot be avoided except in timber from the outside of really large trees. For many purposes "blue-stain" is unimportant, and it has been established that sound wood from dead trees is in no way inferior to that from living trees, and as it is drier it may be actually superior. As dead trees are more liable to attack by fungi and insects than living trees, their timber should be inspected for any signs of infection. If the expense is justified such stock should be kiln-seasoned before use.

In effect, such stereotyped specifications are quite valueless, but many wordings still in use are little better in performing the essential function of a specification, which is to define the quality of materials required. The first essential is that the specification shall be capable of fulfilment, and, secondly, that the conditions laid down are appropriate to the particular case, when it becomes the duty of those responsible to ensure that the specification is, in point of fact, implemented.

THE AMERICAN AND CANADIAN TRADE

The practice in the U.S.A. and Canada is for the producers of different classes of timber to form themselves into Associations, and for the Associations to issue grading rules for their products. Thus in the U.S.A. nearly all hardwood timber is graded in accordance with the rules of the National Hardwood Lumber Association. Softwoods, being more widely distributed, are handled by a larger number of Associations, each with its own rules. For example, there are the Southern Pine Association, the Northern

Pine Manufacturers' Association, the Southern Cypress Manufacturers' Association, the Californian Redwood Association, and the West Coast Lumbermen's Association; each is situated in a different geographical region, and handles different timbers. In Canada the Associations are fewer, but the principles remain the same. Douglas fir, Western hemlock, Western spruce, and Western red cedar, for example, are graded in accordance with the grading rules adopted by the British Columbia Lumber and Shingle Manufacturers, Limited. Canadian hardwoods are graded in accordance with the American Association's rules, and in 1942 the Maritime Lumber Bureau of Nova Scotia issued grading rules for Eastern Canadian spruce.

THE EMPIRE TRADE

Attempts to introduce many new timbers from our tropical colonies to the United Kingdom market have been handicapped by the absence of recognized standards of quality. This has led to official action, and a sub-committee of the Imperial Institute Advisory Committee on Timbers was appointed to examine the position. As a result, grading rules and standard sizes for Empire hardwoods have been evolved on American principles. These rules have been published by the Imperial Institute; they are divided into three sections:

A. Hardwoods from countries other than Canada and New Zealand.
B. Canadian hardwoods.
C. New Zealand hardwoods.

The rules are concerned in detail only with timbers in section "A", the rules of the National Hardwood Lumber Association being accepted for grading timbers in sections "B" and "C". Three divisions are made in section "A": (1) *Standard Grades* (two qualities), (2) *Wormy Grades* (three qualities), and (3) *Grades for Shorts, Squares, Strips, Quarter-sawn stock* (seven qualities).

The Empire rules have been in existence sufficiently long to permit of their practical assessment, and for their shortcomings to become apparent. It seems unfortunate that section A did not follow the American rules more closely, and that they were not evolved from actual study of mill outturn. As it is, the rules provide for an ideal standard, but with many timbers only a small

percentage of the outturn is of this highest standard, and the balance grades not to the intermediate grades, but to the lowest grade provided for. This is because the grades are not well-balanced from the mill output standpoint. Modifications are required to ensure that the outturn can be graded into a series of balanced, progressively lower grades, from prime downwards. The American principle of combining two consecutive grades, stipulating a minimum percentage of the higher grade, would also assist in ensuring workable rules. The Empire rules are destined to give place to local rules, a course that has already been adopted in Malaya and North Borneo.

It remains to be seen how any fixed grading rules will work out in practice in the colonies, except in large-sized European-owned plants. After the initial stages in developing a demand for graded outturn, the work of grading must be handed over to subordinates. These tend to err in one of two directions: they may adhere too rigidly to the letter of the rules, which makes the best of rules unworkable, or they may be too generous to the timber by failing to degrade with sufficient severity. Grading must be carried out with great rapidity for it to be economically practicable, and, as it calls for considerable judgement, besides a very keen eye, it is a highly skilled operation. The introduction of rules is a step in the right direction, but the colonies have a long way to go before grading there can be expected to be in as satisfactory a position as it is on the North American continent

STRESS-GRADED TIMBER

Co-operation between producers is necessary to ensure the working of grading rules, but, as has already been indicated, certain other conditions must be fulfilled. Firstly, the grades must be so balanced that they fit the range in quality of the timber to which the rules apply; secondly, the rules must fill the requirements of the market; and thirdly, there must be a proper appreciation of the significance of defects. Modern grading rules differ in details, but all are based on the evaluation of defects or blemishes.

The significance of defects depends on the purpose to which timber is put, and on the kind of timber. For example, blemishes that mar the appearance of wood, but do not reduce its mechanical

strength, are unimportant in structural timbers, and, conversely, defects that reduce strength properties without appreciably spoiling the appearance of a piece of timber are serious. With decorative timbers the reverse is true, and a defect that reduces strength but does not disfigure the timber, is less important than one that has little effect on mechanical properties but is relatively conspicuous. These facts have long been recognized, and are allowed for in the rules as they stand today. A new departure is the development of stress-grading rules, aimed at ensuring that the timber in each grade shall have certain minimum strength qualities. Again, the evaluation of visible defects is the principle behind the stress-grading rules; the theory has been discussed earlier, *vide* pages 139 to 144.

The British stress-grading rules are covered by conditions laid down in the appropriate British Standards Institution's specifications already mentioned. In a preamble to the rules, their scope and certain terms are defined. Multiplication factors are provided to allow for use of timber in "protected" (1·0), "exposed" (0·85), and "damp" situations (0·70). In other words, where there is an unavoidable decay hazard there is an initial surplus in the strength properties of the timber, which it is presumed will be offset as decay develops, but before it becomes evident. It is presupposed that timber used in such less favourable circumstances will be inspected periodically. The timber must be graded in accordance with its section and length; if re-sawn or cross-cut it must be regraded. The timber is required to be free from certain defects, while the number or size of other defects is proscribed. Sapwood, whether bright or discoloured, is not regarded as a defect in timber used in "protected" positions, *i.e.*, where the timber is protected at all times against wetting by rain or by moisture from the soil or adjacent structures. Minimum weights per cubic foot for the different timbers covered by the rules are laid down; maximum limits in regard to sloping grain are imposed. Dimensions must be full, at 22 per cent. moisture content; and the sizes and tolerances permitted must conform to the requirements of B.S. 1175. Limitations are imposed on the amount of wane [1] permitted; and minimum numbers of rings per inch, varying in different grades, are laid down.

[1] Wane is the reduced thickness and width of a piece consequent on cutting the board or plank to include bark on a portion of one face and edge.

The grades have been designated by the stress symbols *f.* and *c.* The stress symbol *f.* indicates the permissible stress in lb. per sq. in. in the extreme outside fibres of a beam in bending, and the stress symbol *c.* is the permissible stress in compression parallel to the grain in lb. per sq. in. at any point in a column or strut. The grades recognized are: 1200 lb. *f.*, 1000 lb. *f.*, and 800 lb. *f.*, for joists and planks; and 1200 lb. *c.* (European larch and European redwood), 1000 lb. *c.* (European larch, European redwood, and European whitewood), and 900 lb. *c.* (European whitewood), for structural columns and struts. Material graded in accordance with these rules may be presumed to possess the minimum strength properties of the stress grade to which it belongs. Allocation to a particular grade is made on the allowable, visible defects in the piece, which must, in addition, conform with the other stipulated conditions of that grade.

The defects enumerated include knots, knot holes, holes from other causes, shakes, checks, and splits; these have to be measured in certain clearly prescribed ways. Each grade is thus proscribed by the following conditions:

For joists and planks—(a) *knots*: maximum permissible size of knots in the middle third of the length of the piece (the sizes vary with the breadth and depth of the piece); (b) *slope of grain*; (c) *wane*; (d) *shakes, checks,* and *splits* in seasoned timber (varying in size with breadth of piece); and (e) *rate of growth* or number of rings per inch.

For structural columns and struts—(a) *shakes, checks,* and *knots*: maximum permissible size, which varies with the nominal width of surface; (b) *slope of grain*; (c) *wane*; and (d) *rate of growth.*

It is yet too early to form an opinion of the success of stress-grading rules. So far they have not been generally adopted in the United Kingdom, and it is not ordinarily possible to purchase stress-graded timber in the market Such grades have, however, been specified in large Government contracts. The principles are right, but only use of the rules can determine whether the grades selected are practicable or not; it would be just as useful to have 1100 lb. *f*, 900 lb. *f.*, and 700 lb. *f.* stress grades if these should be found to fit the outturn better. Much will depend on whether typical shipments will provide reasonable proportions of each grade, and not only occasional pieces within the limits of

the highest grades, with most falling in the lower grades. Given, however, such rules, timber comes into the realm of engineering materials. We must, however, cease to specify, say, 2 in. by 7 in. joists at 14 in. centres, if, with the new data, the selected stress grade would meet our requirements, and be more economical, were 2 in. by 8 in. material, at 18 in. centres, used.

SPECIFICATIONS

The existence of standardized rules does not obviate the necessity for specifications to define the purchaser's precise requirements, but in the absence of such rules the rôle of specifications is even more important. They serve the dual purpose of defining a client's reasonable demands and the contractor's legitimate liabilities. The simplest course is to specify a particular grade of timber and to add clauses to meet the special requirements of a particular case. This is possible only when recognized grades of the required timber exist — a condition seldom obtaining at present in Britain. Alternatively, the grade may be more vague and the conditions more explicit. Up to the second world war it was sufficient to specify " unsorted, Finnish pine from the Kotka or Uras districts " to ensure a reasonable standard, suitable for carcassing work, although there was nothing like the same assurance of quality, compared with conditions existing thirty years earlier. Similarly, 2nd-quality Archangel was likely to be entirely satisfactory for joinery purposes, but with the same reservation as applied to carcassing material. It is possible that when trading conditions again become normal, a few ports will continue rightly to be known for the high quality of their shipments, but it is most unlikely that this state of affairs will be at all widespread. Moreover, any general tendency to restrict specifications to material from only a few ports would inevitably put enhanced values on such timber.

In the absence of grading rules, it is essential to restrict the number of defects that will be accepted, and to define them in precise terms, in the specification. In this connection the stress-grading rules are an invaluable guide, even in cases where the rules as a whole are not adopted. With a progressive lowering in quality of ungraded timber, it becomes imperative to check the suitability of selected sizes by means of the simple formulae

available. If the scantling sizes call for a value for f. above 800 lb. per sq. in., then nothing lower than the minimum quality provided for in the stress-grading rules is suitable. Alternatively, if a value of only 500 or 600 lb. per sq. in. is required it is almost certain that timber is being used uneconomically.

Besides placing some restrictions on the grade of timber to be supplied, certain general conditions should always be laid down in a specification, together with clauses governing subsequent constructional stages. No standard form can cover all requirements, but instructions under each of the heads given below should be considered in every timber specification.

General.—All timber is to be correct as to species and quality specified. State whether sizes are full, bare, or scant, with limitations in regard to what will be tolerated.

Time of delivery.—Timber to be delivered on the site before any building operations, other than clearing of the site, are commenced, and to be properly stacked under cover in a suitable position.

(Note: if kiln-dried timber is specified, the storage period should be reduced to a minimum, or delivery should be as and when the material is required.)

Storage of timber on the site.—Proper stacking to include the provision of a roof over the stacks of timber, and protection at the sides from driving rain and direct sun; foundations of stacks to be described. The timber in the foundations, and for stickers, to be thoroughly sound, and if of a species susceptible to powder-post beetle attack, absolutely free from sapwood. Size and spacing of stickers to be defined. Stacks of 1 in. material and under to be adequately weighted, and all projecting lengths of timber to be supported beneath and covered above.

Framing of timber.—Timber joints to be well and accurately cut, and all members properly framed together in accordance with drawings.

(Note: full-size, detailed drawings should be supplied for each type of timber joint required, and where members are to be spiked the size and number of nails to be used should be specified.)

Finishing, including wood preservatives.—Provision for inspection before wood is painted or brush-coated with preservatives should be provided for.

The following paragraphs cover typical specifications for (a) a

naturally durable, heavy constructional timber, (b) a moderately durable, medium-heavy constructional timber, (c) a general utility timber, *e.g.*, Douglas fir, European redwood, red meranti, (d) shingles, and (e) plywood ; it is assumed that the plans will incorporate sound principles in regard to the provision of adequate ventilation, and in countries where white ants occur, termite-proof measures. The author ventures to put forward a list of standard defects at the end of the timber specification ; local conditions may suggest modifications of this list. Timbers to be used should be specified by their standard trade names ; defects known to be common in the selected timbers should be specially referred to, and the extent to which such defects will be admitted must be defined.

Naturally durable, heavy constructional timbers.—All timber in contact with the ground is to be of [a named timber], or other approved hardwood, and all scantlings are to be thoroughly sound, full to thickness, well cut and with parallel edges. The timber is to be planed all round, and is to be absolutely free of defects except in regard to the following, which shall be allowed :

(a) Bends not exceeding 1 in. in 12 ft run.

(b) Sapwood not exceeding $\frac{1}{8}$th of the width of any face and restricted to not more than two faces ; the sapwood is to be adzed off before fixing.

(c) " Pin-worm " holes, *i.e.*, galleries not exceeding $\frac{1}{32}$ in. in diameter, shall not count as a defect provided they are old and inactive and that the surrounding timber is thoroughly sound.

(d) One standard defect in lengths of 8 to 12 ft, two standard defects in pieces 12 to 16 ft long, and three standard defects in pieces over 16 ft long. For the purpose of this specification sapwood and " pin-holes " are excluded from the list of standard defects, being limited by clauses (b) and (c) respectively.

Moderately durable, medium-heavy constructional timbers.—(i) *Shingle or tiling battens* : [a named timber], or other approved timber, is to be used for shingle battens ; it is to be thoroughly sound, absolutely free from sapwood, 2 in. by 1 in. nominal sizes, well cut, and with parallel edges ; the following defects will be permitted :

(a) Bends not exceeding 1 in. in 12 ft run.

(b) Not more than twelve " pin-worm " holes, *i.e.*, galleries not exceeding $\frac{1}{32}$ in. in diameter, will be allowed in any foot run on the worst face.

(c) One standard defect in lengths of 8 to 12 ft, two standard defects in pieces 12 to 16 ft long, and three standard defects in pieces over 16 ft long. For the purpose of this specification sapwood and " pin-holes " are excluded from the list of standard defects, being limited by clause (b) and the preamble.

(ii) *Framing and other carcassing timber* : [a named timber], or other approved timber. All timber other than posts in contact with the foundations, shingle battens, flooring and joinery, is to be of [a named timber], or other approved timber selected by the architect. It is to be thoroughly

sound, well cut, and with parallel edges, framing to be planed all round; sizes are nominal.

Every piece is to be absolutely free of defects except in regard to the following, which will be allowed:

(a) Bends not exceeding 1 in. in 12 ft run.

(b) Sapwood not exceeding ⅛th of the widest face and ⅛ in. of any one other face of the same piece.

(c) One standard defect in lengths under 8 ft, two standard defects in pieces 8 to 12 ft long, three standard defects in pieces 12 to 16 ft long, and four standard defects in pieces over 16 ft long. For the purpose of this specification, sapwood is excluded from the list of standard defects, being limited by clause (b).

General utility timbers.—Flooring and joinery is to be of [a named timber], or other approved timber selected by the architect. It is to be thoroughly sound, well cut, and have parallel edges; flooring is to be planed on one face and both edges, and all other timber in this section is to be planed all round; sizes are nominal. Every piece is to be absolutely free of defects except in regard to the following, which will be allowed:

(a) Bends not exceeding 1 in. in 12 ft run.

(b) Sapwood not exceeding ½ in. on any face, but allowing a total of 1 in. plus the thickness of the piece if confined to one edge.

(c) Not more than four "shot-holes", *i.e.*, galleries up to ⅛ in. in diameter, in any foot run, and an average of not more than one per foot run of total length in 50 per cent. of the material, the remainder to allow an average of not more than two "shot-holes" per foot run of total length.

(d) Except in flooring timber, slight "spongy heart" will be allowed provided no visible compression failures are present; flooring timber is to be free from all visible traces of "spongy heart".[1]

(e) One standard defect in lengths under 8 ft, two standard defects in lengths of 8 to 12 ft, three standard defects in lengths of 12 to 16 ft, and four standard defects in lengths of over 16 ft. For the purpose of this specification sapwood and "shot-holes" are excluded from the list of standard defects, being limited by clauses (b) and (c) respectively.

Shingles.—The shingles are to be best quality, split (or quarter-sawn), seasoned [a named timber] shingles, purchased from a firm selected by the architect; shingles are to be pre-bored before fixing (this clause applies to billian or other hardwood shingles and not to western red cedar). They are to be laid to a lap equal to one-third of their length (a greater lap may be allowed if double coursing is specified), with a clear space of $\frac{1}{16}$ in. to ⅛ in. between each shingle; no vertical joint in any three successive rows shall coincide but shall be staggered not less than one-third of the width of a shingle.[2]

Plywood.—Inner cores of plywood shall be of Douglas fir or other approved softwood, or of a timber immune to powder-post beetle attack;

[1] If the flooring timber selected is a species susceptible to powder-post beetle attack, complete freedom from sapwood must be specified; this precaution also applies when such timbers are to be used for joinery, panelling, and fittings.

[2] If stained or treated shingles are required, such treatments are to be applied before fixing. If the species is one susceptible to powder-post beetle attack, freedom from sapwood must be specified unless the shingles are to be pressure-treated.

the surface veneers shall be free from sapwood unless of a species immune from powder-post beetle attack.[1] The cementing matrix shall be a casein glue or other approved adhesive. All external plywood to be resin-bonded plywood of external grade quality.

SUGGESTED STANDARD DEFECTS

The following is a list of standard defects :

Item	*Equivalent number of standard defects*
Knots	
One sound knot $\frac{5}{8}$ in. to $1\frac{1}{4}$ in. in diameter or equivalent	1
One sound knot over $1\frac{1}{4}$ in. to $2\frac{1}{2}$ in. in diameter or equivalent	2
One sound knot over $2\frac{1}{2}$ in. to $3\frac{1}{2}$ in. in diameter or equivalent	3
Two knots, each under $\frac{5}{8}$ in. in diameter or equivalent	1
Three knots, all under $\frac{5}{8}$ in. in diameter or equivalent	2
Worm holes	
One or more "pin-worm" holes, *i.e.*, galleries up to $\frac{1}{32}$ in. in diameter, in a group not exceeding $1\frac{1}{4}$ in. in diameter	1
One or more "shot-holes", *i.e.*, galleries up to $\frac{1}{8}$ in. in diameter, in a group not exceeding $1\frac{1}{4}$ in. in diameter	1
One bore-hole (or gallery) other than a "pin-worm" hole or "shot-hole" not exceeding $\frac{1}{4}$ in. in diameter	1
One bore-hole (or gallery) other than a "pin-worm" hole or "shot-hole" but exceeding $\frac{1}{4}$ in. in diameter	2
Split	
One end split, or splits at each end, not exceeding in total length in inches half the lineal measure of the piece in feet ; each split opening out not more than $\frac{1}{8}$ in. per foot of length	1
One end split, or splits at each end, not exceeding in total length in inches the lineal measure of the piece in feet ; each split opening out not more than $\frac{1}{8}$ in. per foot of length	2
Sapwood	
Sap on species not exceeding $1\frac{1}{2}$ in. in thickness :	
(i) If 6 in. or over in width, not exceeding $\frac{3}{4}$ in. on any face, but allowing a total of $1\frac{1}{2}$ in. plus the thickness of the piece if confined to one edge	1
An additional $\frac{1}{4}$ in. of sapwood as above shall be considered as equal to a total of two defects.	
(ii) If under 6 in. in width, $\frac{1}{2}$ in. on any face, but allowing a total of 1 in. plus the thickness of the piece if confined to one edge	1
An additional $\frac{1}{4}$ in. of sapwood as above shall be considered as equal to a total of two defects.	

[1] If the plywood available does not conform to this specification, the edges of the sheets must be adequately treated with a suitable wood preservative.

Sap on pieces exceeding 1½ in. in thickness :

(i) Sapwood on not more than three faces and in width on any face not exceeding ⅛th of the width of that face . . 1

(ii) Sapwood on not more than three faces and in width on any face not exceeding ¼ of the width of that face . . . 2

(Note : it will be apparent that the grade of a piece of wood can be improved if defects are cut out by trimming the piece ; trimming is regularly practised in American and other up to-date mills.)

Other conditions than quality of the timber are of practical significance. Chief among these are the moisture content of the timber and the condition of the building at the time the timber is to be installed. Requirements as to moisture content are specified on pages 102-3 and 107, but equally important is the state of dryness of the building. It is sometimes economical to install temporary heating before fixing second fixings. Special instructions must be given regarding the drying of timber to the correct moisture content if air-conditioning is to be installed : only two ways of drying the timber adequately are available, one being in a kiln and the other in an air-conditioned chamber. Furniture suitable for ordinary atmospheric conditions will suffer serious degrade in air-conditioned rooms if the moisture-equilibrium conditions of the latter are lower than normal, which they are most likely to be.

The recommendations made above provide for considerable stiffening of specifications for timber acceptable for building work ; more latitude than is allowed at present may be granted in a few directions, *e.g.*, the use of sap-stained timber where sapwood is not objectionable, the use of pin-worm material. Where appropriate British Standards exist the timber should be required to conform to the appropriate Standard, the number and date of which should be cited. If this procedure is adopted it should suffice to specify the Standard and the name of the timber required, indicating, where they exist, whether any permissive clauses in the Standard shall apply. Where timber absolutely free from sapwood is required, *e.g.*, joinery and flooring in *Lyctus*-susceptible hardwoods, it should be so specified, and a rider added that the condition will be rigidly enforced. In general, such meaningless phrases as " well-seasoned timber " should be omitted and the moisture content range required specified.

CHAPTER XVII

WOOD AS AN ENGINEERING MATERIAL

Variability in wood undoubtedly imposes limitations on its uses, but an understanding of the variation discussed in Chapter VII is probably of more importance to the grower of timber, that is, the forester, than it is to the consumer, be he architect or engineer. Fortunately, with the knowledge that variability exists, and some knowledge of its extent, it has been possible to overcome the limitations imposed. The data for strength properties, and the development of stress-grading rules from such data, coupled with the use of timber connectors and modern adhesives, have rendered strength variations of secondary importance in modern timber design. Moreover, these developments place timber today in the field of engineering materials, more modern even than steel or reinforced concrete. In fact, it is the newest material available, with many advantages on economic grounds over its competitors. This has attracted the interest of a few structural engineers who see an almost limitless new field for wood. The writer has borrowed freely from the writings of one of these, Mr. P. O. Reece,[1] in the following paragraphs.

Timber has been used as a structural material from the earliest times : examples can be traced to the neolithic era, dating back to about 8000 B.C., but it was not until 1678, when Robert Hooke established the fundamental relation between stress and strain, that any adequate theory was available to guide designers. For another two hundred and fifty years little scientific knowledge accumulated to aid timber utilization ; it remained a material for the craftsman, and the engineering formulae developed for it in this period were based on little more than empirical practice. Between the two world wars the whole position changed : an

immense volume of data relating to the strength properties of timbers was collected, but these data have, as yet, been very sparingly applied.

Regarded as an engineering material, the approach to wood must be quite different from past practice : there are many yard-sticks to apply, but one of the first described by Reece is specific

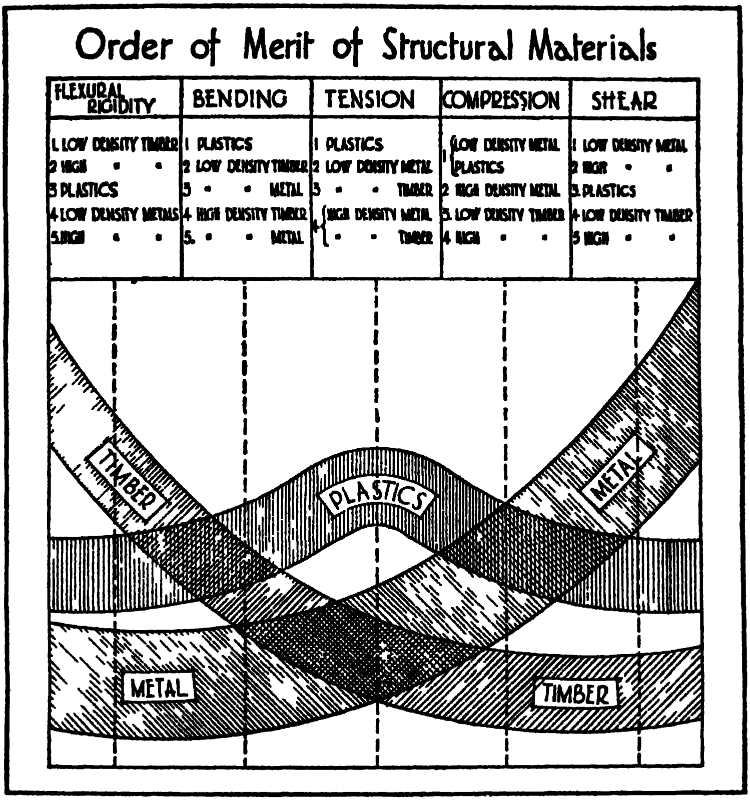


FIG. 42 —" The broad shaded bands lie one above the other in order of merit, and varying in their relative positions, depending on the nature of the stress Thus, for flexural rigidity the order is timber, plastics, and metals , in shear, metals, plastics, and timber , and so on . in each band the upper limit represents low density forms of the particular material, and the lower limit the high density forms " (*loc cit.* p 120)

By courtesy of P O Reece, Esq

strength ; that is, the ratio of strength to unit weight. A second criterion must be that of cost ; the comparison here is the ratio of weight to cost.

Specific strength must, of course, be separately calculated for

strength in compression, in tension, and in shear. Moreover, as few structural members are used in pure compression, tension, or shear, flexural considerations that cannot be divorced from size and geometrical properties of these members must be studied. It has been established that, for geometrically similar sections of equal weight, the cross-sectional area varies inversely as the density, and the section modulus varies inversely as the density raised to the power of 1·5. The specific strength in bending is, therefore, the stress divided by the density raised to the power of 1·5. When deflection is a governing condition, strength is a function of the flexural rigidity factor: modulus of elasticity multiplied by the moment of inertia of the section, or simply EI. The moment of inertia varies inversely as the square of the density. Hence, the specific strength of members governed by deflection limitations is the modulus of elasticity divided by the square of the density.

Working from the foregoing premises, Reece examined the comparative efficiency of five different structural materials subjected to different kinds of stresses. From this analysis he constructed the pictorial order of merit chart illustrated in Fig. 42. From the chart the superiority of timber in flexural rigidity is immediately apparent, rendering it pre-eminent for all structural components that can fail from elastic instability, *e.g.*, slender, lightly-loaded columns; long, lightly-loaded beams; stressed-skin construction, where the covering or panel-filling material is utilized to stiffen the framework; and, in general, all components that are lightly loaded in relation to their size.

Next, Reece has provided a comparison between the loads that solid, circular-section, timber struts of different lengths will carry, and those that rolled steel joists of equal weight and similar lengths would support, *vide* Fig. 43; the advantage is with steel for very short lengths, but becomes reversed as the slenderness ratio comes into play.

Another interesting aspect of the peculiar properties of wood, which has come to light as a result of scientific testing of timber, is the effect of duration of loading. If a value of 100 is taken for the ultimate stresses for loads sustained over periods of 40 to 50 years, for a period of one month the figure would be 130, for an hour over 150, for five seconds nearly 200, and for impact loading 250. These results, compared with similar data for other materials,

show timber to be particularly suitable under short-time loading conditions, as in roof construction, towers, pylons, high single-storey buildings, of the hangar type, where the main problem is the accommodation of high wind loads for very short periods. Similarly, most floors, other than warehouse floors, are loaded to

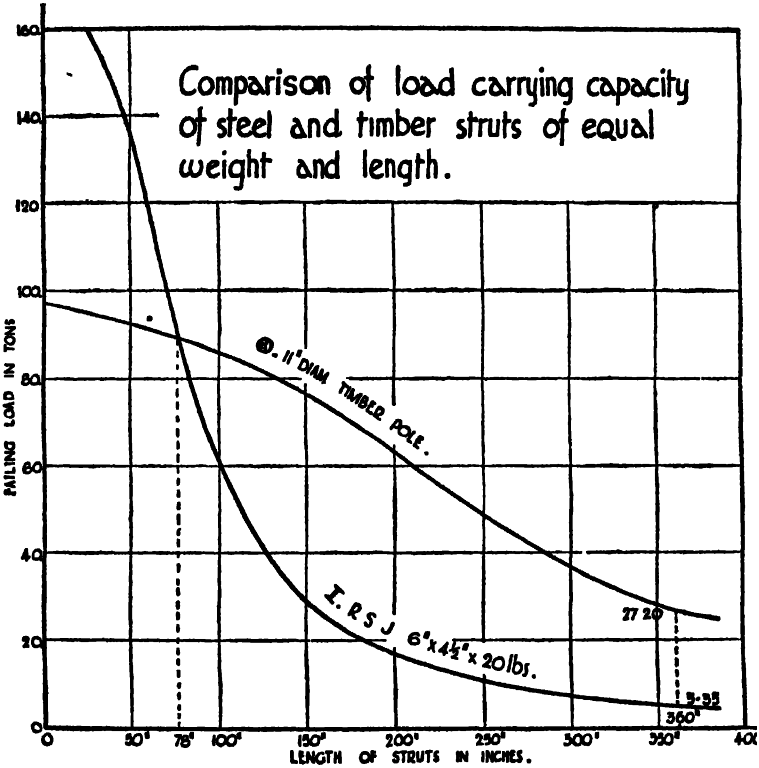


FIG. 43.—Strength properties of wood and steel compared
By courtesy of P O Reece, Esq

capacity only for brief periods, and this makes timber a particularly suitable material for floor construction.

Analysis has confirmed the correct usage of timber by craftsmen, except for excessive generosity in sectional area of members. On the other hand, when steel became available its introduction into timber trusses for tension members, but not for the short members subjected to compression, was apparently at variance with correct usage, which suggests the retention of timber for tension members and their replacement by steel for short, thick

compression members. The reasons for the foregoing practice are bound up with the serious effect on tensile strength of knots, and the loss in strength that results from cutting away of timber to form joints. More recent developments have provided a solution to both objections, namely stress grading, timber connectors, and modern adhesives.

TIMBER CONNECTORS

The ease with which timber can be fabricated has contributed enormously to its usefulness, but joints and fastenings have always been the weak link in timber construction. Many carpentry joints necessitate reducing the cross section of a member, thereby reducing the strength appreciably compared with the full sectional area. Elaborate carpentry joints that reduced loss in strength of jointed members to a minimum were developed by our ancestors, but for most purposes these became altogether too expensive when labour costs began their upward trend after the Industrial Revolution. Instead, bolts, and sometimes only a few nails, replaced good practice, frequently with loss in strength, because there was no suitable method available to replace the older empiricism. Simple bolt fastenings, although preferable to random nailing with an unspecified number of nails of indeterminate quality, reduce the strength properties of each piece of wood by the amount of timber cut away to take the bolts. Moreover, the strength of the joint is less than that of the bolt, as failure is generally induced either by shear through the timber at the bolt-hole, or through crushing of the timber bearing on the bolt itself.

The high stresses around the bolt-hole were early recognized to be a weak point of bolted joints: solutions were sought by means of bushings around the bolt, aimed at increasing the bearing area. Efforts made in this direction have given rise to modern rings, toothed plates, and variously shaped discs.

An American patent was granted as early as 1889 for a toothed plate for joining timber, and it is recorded in the U.S. Department of Commerce bulletin, *Modern connectors for timber construction* (1933), that even earlier than this cast-iron rings were used in American bridge construction. The years 1916 to 1922 produced

urgent constructional problems that resulted in real progress being made in the evolution of suitable mechanical devices for improving timber joints, which are now generally referred to as timber connectors, although the majority are actually pieces of metal. Originating in Europe, modern timber connectors reached the U.S.A. in 1930, since when rapid advances have been made, and the scope for timber construction has been greatly widened.

More than sixty different types of connectors have been patented in Europe, and in several cases U.S. patents have also been obtained. All embody the same principle, which is to increase the area over which the load at the joint is transmitted,

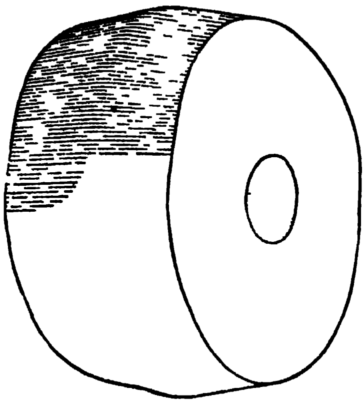


FIG. 44.—The Kubler dowel

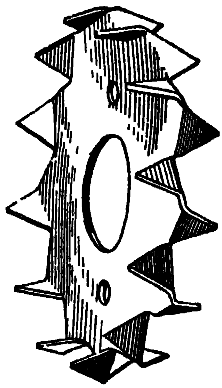


FIG 45.—A bulldog timber connector

thereby minimizing crushing of the timber by the bolt, and the tendency for shear failure at the bolt-hole. Connectors are, however, conveniently divided into two general types: connectors stressed chiefly in shear, *i.e.*, short dowels and auxiliary connectors other than dowels, and those that have to sustain a certain amount of bending in addition to shear, *i.e.*, long bolts and dowels.

The first timber connector was the Kübler dowel (Fig. 44), evolved in Germany; appropriately enough, it was made of wood. The dowel itself, which was of hardwood, was doubly conical, being widest in the centre, and therefore at the point of contact of the two pieces of wood to be jointed; it was bored longitudinally to receive a bolt. Both timbers had to be recessed to take the dowel, which necessitated much cutting to house the conical ends of the dowel satisfactorily, and to secure a flush

bearing surface between the two members. The dowel, however, increased the bearing surface appreciably, compared with a single bolt, thereby reducing crushing of the timbers by the metal bolt.

The Kübler dowel was later followed by a steel ring, working on the same principle, but weakening the timber less by reason of the small amount of cutting necessary for recessing a thin ring, compared with a thick, conical dowel. Moreover, cutting of the recess was greatly simplified and much less costly. About the same time O. Theodorsen, of Oslo, patented the **bulldog timber connector** (Fig. 45), which, with slight modifications, is still widely used. The bulldog connector consists of a round or square steel plate, punched at the centre to take a bolt, and with the perimeter turned alternately upwards and downwards to provide triangular teeth. The timbers to be jointed are bored to take a bolt, the connector is inserted between the two members, and the bolt slipped through. As the nut is tightened the teeth of the connector bite into the wood. It is a comparatively simple matter to tighten the bolt when the connector is used with softwoods, but with hardwoods it is usually necessary to hammer the teeth of the connector into one of the timbers, and to use a bolt with a shank of high tensile steel that will permit of the nut being tightened while the teeth are pressed into the opposite member. Once drawn together, with the teeth of the connector ring embedded, the special bolt can be replaced by an ordinary one.

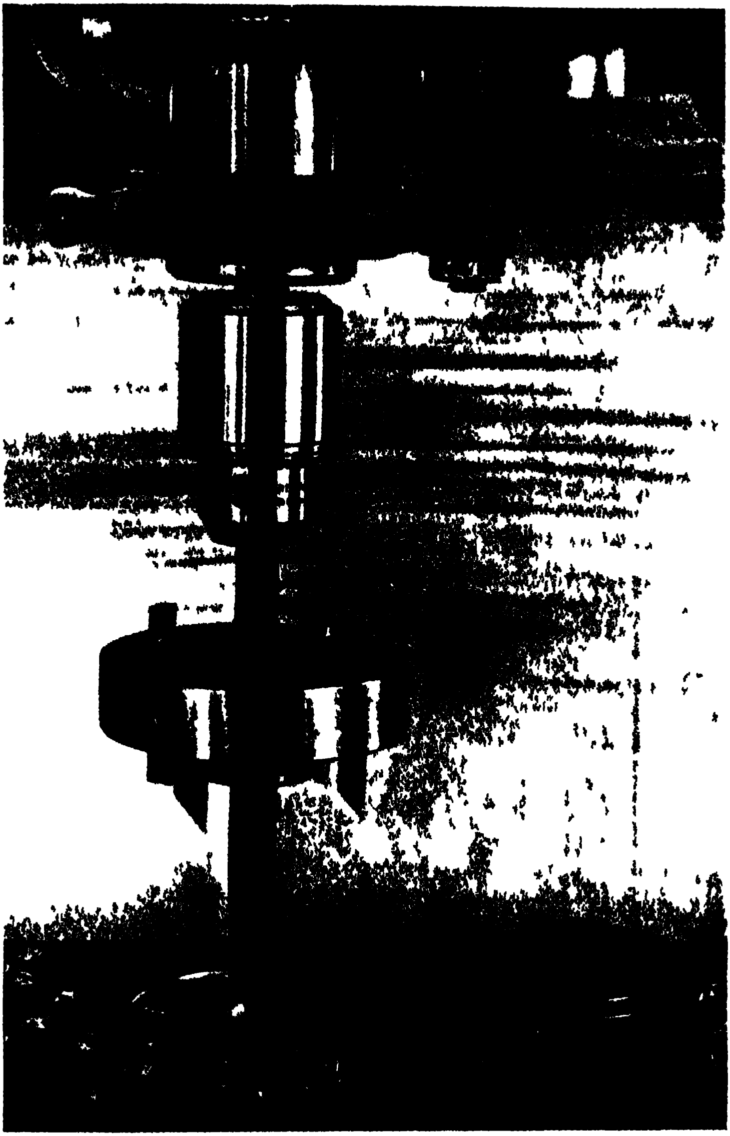
Bolt fastenings of connectors are used in conjunction with large metal washers or plates to prevent the bolt head or nut from pulling through the bolt-bole. Power-operated tools have been designed for cutting the special shaped recesses required for different connectors, and for boring the bolt-holes, which greatly facilitate the fitting of connectors. Power-operated assembly tools are available for further accelerating assembly of modern timber connectors.

Connectors stressed chiefly in shear come into one or other of the following categories :

(1) **Split ring connectors** (Plate 62) fit into pre-cut grooves of opposing members, which in turn are drawn together by a centre bolt which is completely independent of the ring.

(2) **Toothed-ring connectors** (Plate 63), the teeth of which are forced into the timber as the two members are drawn together by the securing bolt, which (as with the split ring connector) is

PLATE 62



A split ring connector, showing the portable pneumatic drill for cutting the recess and boring the bolt hole. Manufactured by the Timber Engineering Co., Washington, D.C.

[illegible]

PLATE 63

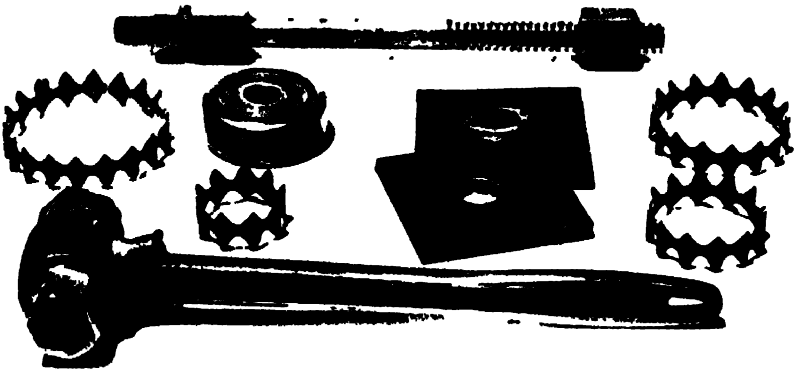


FIG. 1. Toothed rings, washers, and assembly apparatus

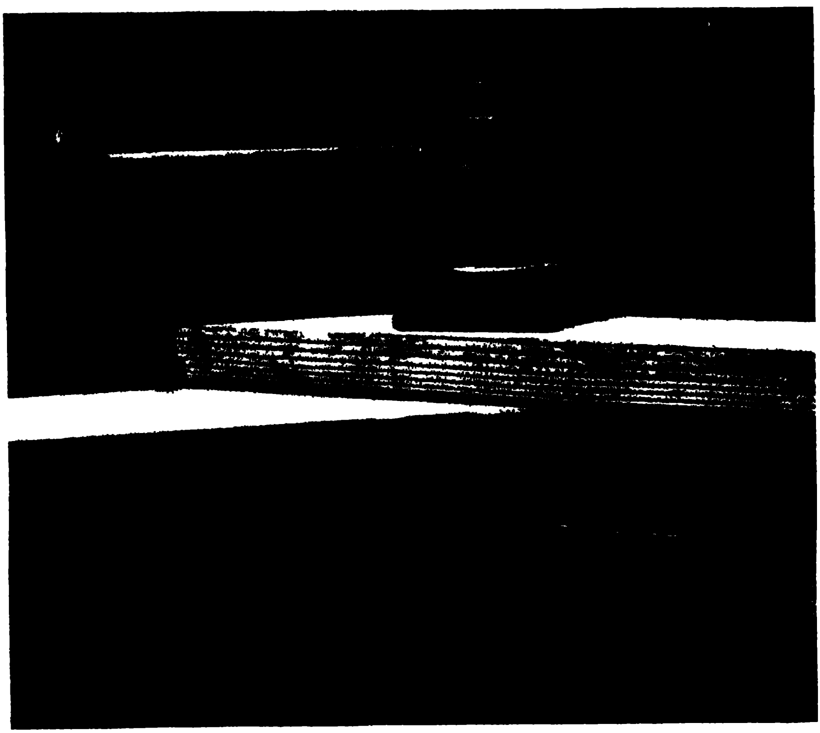


FIG. 2 Tightening a toothed-ring connector joint

By courtesy of the Timber Engineering Co., Washington, D.C.

completely independent of the toothed ring.

(3) **Claw-plate connectors** (Plate 64, fig. 1), a development of the bulldog connector, which fit into pre-cut recesses; the claw plate has protruding teeth that are pressed further into the wood as the bolt is tightened. Claw plates are used singly in timber to metal joints, and in matched pairs—male and female claw plates—in wood-to-wood joints. In the Teco claw plates[1] for timber-to-timber joints the outside hub (on the face opposite the teeth) of the male plate consists of a central boss that slips into the recess of the hub of the female plate. A large bolt fits the

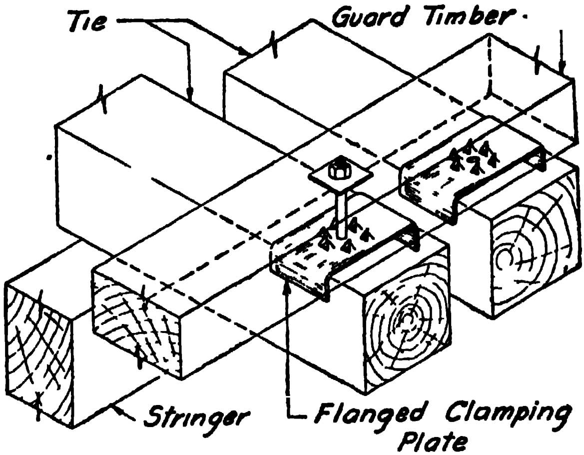


FIG. 46 --Use of a Teco clamping plate

By courtesy of the Timber Engineering Co

hub snugly, the connector being flush with the adjacent surfaces of the members joined.

(4) **Shear plates** (Plate 64, fig. 2) are also flush-fitting connectors for wood-to-wood or wood-to-metal joints. A circular recess, with a sunken margin, is cut in the timber (in both timbers for a wood-to-wood joint) to receive the shear plate, which consists of a circular steel disc, bored centrally to take a bolt and with a raised rim on one or both sides. The plate is tapped into place with a hammer, and the bolt dropped into position and tightened.

In the split ring and toothed-ring connectors the load is transmitted by shear, more or less independently of the bolt,

[1] Manufactured by the Timber Engineering Company, 1319 Eighteenth Street, N.W., Washington, D.C.

whereas the claw-plate and shear-plate connectors are dependent on the bolt for transmitting load by shear from member to member.

Other modifications of the bulldog connector on the market are the Teco spike grids (Plate 65), and the Teco clamping plates (Fig. 46) designed for special uses; the illustrations are self-explanatory.

Connectors, other than nails and bolts, that have to sustain a certain amount of bending as well as shear are of two types. In the Meltzer steel tack, developed in 1910, several steel pins of small diameter replace a few large-diameter bolts. Holes of the exact diameter of the pins are drilled through the members to be joined, and the pins inserted; the pins are without heads or nuts, friction being counted upon to hold members together. Meltzer joints of strength comparable to bolt joints effect appreciable savings in weight of metal used, the more numerous steel pins weighing half that of the requisite number of bolts. The second type is the Cabröl method employing a metal pipe. The joint is bored to take a hollow pipe, the ends of which are covered, after fixing, to exclude moisture. Metal bearing plates are used between the pipe and the wood-filler blocks that transmit the stresses to other pins.

Scholten [1] has listed the principal advantages of connector joints, which may be summarized as follows:

1. Relative high efficiency of joint compared with carpentry joint.
2. Relatively simple and practical application.
3. A minimum number of units or pieces to handle in the erection stages. (Compared with single bolts there may be more pieces in the assembly stage when connectors are used.)
4. Adaptability to prefabrication for subsequent field assembly
5. Connectors give a better performance when used under adverse conditions than bolts or nails (water-proof glues may be superior).
6. Improved appearance of connector joint over exposed metal strapping.

PLATE 64

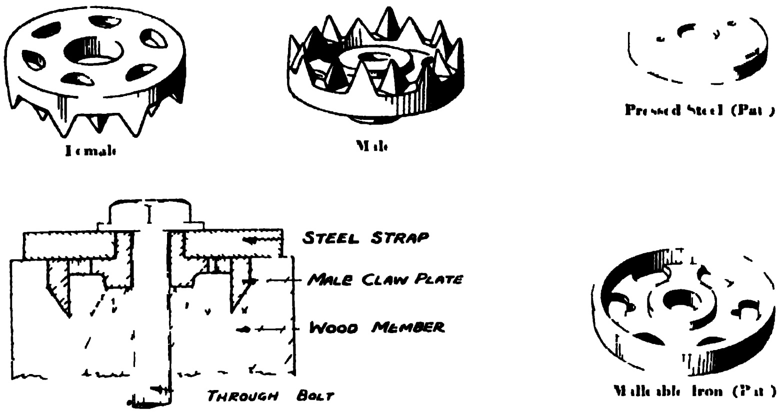


FIG. 1. Top left: male and female claw plate and below, the use of a male claw plate. Top right: two types of shear plates.

FIG. 2. Shear plates in position.

By courtesy of the Timber Engineering Co., Washington, D.C.

PLATE 65

The Teco spike grid. A horizontal member secured to a round pole by means of a spike grid

By [illegible]

7. Greater fire resistance of connectors over strapping because embedment of connectors in wood reduces amount of metal exposed to fire temperatures.

On the debit side, the special tools required, preferably power-operated, for cutting recesses for the split ring, claw-plate, shear-plate, and bulldog connectors, are a disadvantage in small jobs because of their cost.

In evaluating the merits of connector joints it is desirable to compare the strength of such joints with the various alternative methods of metal fastenings. Reece[1] has done this, comparing the bearing strength in a simple double lap joint of Douglas fir, 2 in. minimum thickness, provided by various types of fastenings. He found that equal bearing strength is provided by—

Two $2\frac{1}{2}$ in. bolted split ring connectors
Ten $\frac{1}{2}$ in. diameter bolts
Eight 2 in. bolted hardwood dowels
Eighteen $\frac{1}{4}$ in. diameter wood screws
Twenty-six $\frac{1}{8}$ in. diameter wire nails

Reduction in number of fastenings required effects considerable saving in assembly costs, but, compared with nails, the advantage of connectors lies in the greater reliability with which the strength of the joints can be determined.

Working loads of connectors elude precise mathematical calculations, and have had to be built up from test data. The process has required accurate and comprehensive strength tests of actual joints, which have provided figures suitable, when modified by appropriate factors of safety, for use as safe working loads in constructional design.

The evolution of a strong and reliable joint was responsible in itself for widening the scope of timber construction, by making possible designs that were quite impracticable so long as much weight was wasted in framed members that could develop at the joints only a fraction of their overall strength properties. Moreover, connectors permitted the use of many small-sized members, instead of a few large-dimension ones, greatly widening the field from which the raw material could be drawn, and, incidentally, the cost of the necessary timber. These facts, coupled with the

[1] P. O. Reece, *loc. cit.*

era of scientific investigation of the strength properties of wood that resulted in the evolution of stress grading, have transformed wood into a precision material that an engineer-designer can use as an alternative to steel or reinforced concrete. Often timber will provide a better solution from the engineering standpoint, and invariably at less cost, in timber-producing countries.

ADHESIVES

The most recent aid to the utilization of wood as an engineering material has come from developments in adhesives since 1930. Gluing of wood to wood has been practised since very early times, but modern glues are very different from the joiner's glue-pot that has persisted, often in more senses than one, for hundreds of years. Even primitive glues, however, had a considerable influence on the utilization of wood: the Egyptians practised marquetry with veneers of contrastingly-coloured woods around 1500 B.C. The art of veneering was revived in the 17th and 18th centuries as a result of the invention of wood-cutting machinery: the first mechanically-operated saw came into use about 1650, a circular saw was patented in 1775, and a bandsaw in 1808. In 1793, Sir Samuel Bentham patented a series of wood-working machines, one of which was designed to produce veneers intended for gluing together, and therefore heralding the product we now know as plywood.

Veneering was an attempt to widen the decorative scope of natural wood, and not a resort adopted to cover up inferior materials or workmanship. Glue was an essential adjunct to this decorative use of wood, and the then existing glues were adequate for the purpose. Gluing for constructional ends was a much later development. Plywood as we know it today was initially developed for decorative ends, and was the outcome of improvements in machinery. In the first American patent taken out in 1868, however, specific mention is made of the improved strength properties of the resultant product, compared with ordinary wood:

"The invention consists in cementing or otherwise fastening together a number of these 'scales'[1] or sheets, with the grain of

[1] Scales was the name given to the sheets of veneer.

the successive pieces, or some of them, running crosswise or diversely from that of others. . . . The crossing or diversification of the direction of the grain is of great importance to impart strength and tenacity to the material, protect against splitting, and at the same time preserve it from liability to expansion or contraction." [1]

The use of plywood as a trade name for the material may be traced to the war years 1914–18. The earliest uses were for furniture, and later joinery and packing-case material; its use for constructional purposes was dependent on the evolution of water-proof glues — synthetic resin products — that made their appearance in 1930. Previous to this, existing glues often secured, at least for a time, a bond between two timber surfaces equal to the cohesion of the cells in a piece of wood; many glued panels of inadequately seasoned wood have split instead of separating along the glue line. The qualification "for a time" is, however, all-important; it restricted the use of glued material constructionally.

Research into the properties of adhesives has been responsible for the strides made in recent years. Scientific investigation has established that adhesion between two solid bodies may be of two kinds: (1) natural or specific adhesion produced by molecular forces of the same kind as those holding together the molecules of any solid body, and (2) mechanical adhesion by the setting of an adhesive that has obtained a key by filling crevices in two adjacent glued faces. The natural adhesion between two super-finished surfaces is of a very high order, *e.g.*, the force required to separate two planes of glass, when in contact, is in the region of 90 tons per square inch.

Certain glues function in both ways, and with most modern glues the adhesive has a shearing strength greater than that of wood. There are additional factors that influence the strength of glued joints: firstly, the smoother prepared surfaces are made prior to gluing, the better will be the results; and secondly, with two surfaces offering the minimum rugosity, maximum joint strength is secured with the thinnest possible glue line. These findings are in keeping with the theory of natural or specific adhesion. It has, however, been established that in gluing birch veneers with phenolic glues penetration of the veneer by the

glue, and hence mechanical interlocking, does undoubtedly occur. The time-lag between preparing the surfaces for gluing and completing the operation is also important, although the chemical and physical reasons for this are obscure. Veneers that have been in stock for a considerable period after finishing often yield bad joints, because the long-exposed surface fails to accept the glue properly. This processing difficulty is known as "case hardening", the term being used in a different sense from the stressed condition of timber that may occur in the course of seasoning (*vide* page 205).

In the evaluation of joint strength it is particularly important to take into account the glue-line thickness. With special-purpose adhesives, satisfactory joints have been made between two surfaces up to 0·05 in. apart, but the conditions prevailing in such **gap joints**, as they are called, are very variable and often quite impossible to predict. Crazing and discrete points of contact are defects to be guarded against: selection of a suitable adhesive and attention to processing technique are important in such circumstances.

So long as the glue undergoes no change the strength of a glued joint tends to be governed today by the dimensions and physical properties of the wood used, and by the shape of the joint, rather than by the qualities of the particular glue selected, although, as has just been indicated, gluing technique is important. Glues with the requisite initial strength have now been evolved that are also proof against damp, the ravages of micro-organisms, and the lapse of time: they are as stable and durable as the timbers they join. Not all modern glues possess these desirable characteristics, and of the most durable, which are phenol formaldehydes or derivatives or homologues of phenol reacted with suitable aldehydes, some have the disadvantage of necessitating high temperatures and pressures to secure setting; these requirements are impracticable in many gluing operations.

Glues may be classified in the following categories:

Animal glues: skin or hide glues, bone glue, extracted bone glue, and rendered glue.—The adhesive in all cases is an organic substance called collagen. The merit of these glues is simplicity in use. Being subject to attack by micro-organisms, they lack durability, and lose their adhesive properties if exposed to damp.

Casein glues are derived from skimmed milk, the adhesive

being a protein product. To improve the water resistance of these glues it is now usual to add various compounds such as sodium and calcium hydroxides, sodium silicate, and certain copper salts. More recently, formaldehyde and urea have been added to give "improved" casein glues. The group generally has the merit of simplicity in use, good strength, and lasting qualities. The resistance and durability of properly mixed casein glues, properly applied to adequately prepared surfaces, are such as to justify the continued use of these glues for interior work. Exposure to damp is liable to cause chemical breakdown and bacterial attack, with consequent loss in strength of the glued joint.

Heavy laminate structures, made up with casein glues, have, however, been used for exterior purposes with success over quite long periods. This must not be interpreted as justifying the use of casein-glued plywood for exterior sheathing under conditions of full exposure to the weather: for such conditions even plywood bonded with the so-called water-proof glues is inadequate, and only genuine exterior grades should be employed.

Extracted soya bean flour is another protein glue of modern origin with similar properties and limitations to casein glue.

Starch and soda silicate glues.—The basic ingredients are dry cassava flour, caustic soda, and water, to which may be added various chemicals to improve the low water resistance of this type of glue. In the absence of damp conditions the adhesive qualities are good, but the glues are not suitable for brush spreading.

Synthetic resin glues.—Phenolic and urea formaldehydes are at present leaders in the field of synthetic resin glues; they usually require high temperatures and pressures to secure good bonding. Many modified products have been evolved, aimed at reducing the cost of these glues, which is relatively high, and overcoming the need for high temperatures and pressures. Most of the modifications so far available are at the expense of extreme durability, resistance to damp, and bacterial action, and a wide range of temperatures: for the present the only absolutely reliable water-impervious glues are the derivatives of phenol. Already, however, several melamine glues have met the very stringent tests of B.S.I. 1203 and 1204 in regard to water resistance.

There are other types of synthetic resin glues than the phenolic and urea formaldehydes that may prove to be of high importance,

but data from exposure tests of sufficient duration are not available to permit of a final assessment of their true worth. For example, formvar, a derivative of polyvinyl alcohol, gives a joint strong enough to pass the A.I.D. Test for propeller manufacture, and polyvinyl acetate, and modifications of this, also give a range of useful adhesives. More recently, vinyl derivatives, used in association with synthetic and natural rubber lattices, have come to the fore.

Modern glues have greatly increased the scope for wood, and laminate construction (gluing of relatively thin layers of wood together) and block boards (small cubes or rectangles of wood glued together) have entered many fields previously restricted to solid wood construction or alternative materials, proving themselves superior and less costly. The next stage is built-up construction or glued laminated construction — combining laminations, adhesives, and connectors, which gives freedom to the designer, besides scope for using material that would otherwise be too small for structural purposes. Large spans can be bridged with built-up arches and girders much more satisfactorily than with solid timber, and at considerable savings in cost, compared with steel or reinforced concrete. All these developments have hinged on progressive improvement of glues. In Reece's words: "Gluing does for timber what welding does for steel; it enables joints to be made without cutting any material out of the members joined and makes it possible for the designer to take advantage of all the economies associated with monolithic construction".[1]

Mention has already been made of the use of synthetic resins in a different capacity from that of adhesives in the popular sense (*vide* pages 106 and 245). Impregnation of wood with these products, followed by the application of pressures of a high order, give a product with phenomenal strength properties. The resultant material is not, however, wood in the sense discussed here. It is conceivable that this improved wood may be used with untreated wood and laminated material to extend still further the scope of both in engineering construction.

Summarizing the position: firstly, fundamental research into the strength properties of wood has pointed the way to rapid visual assessment of the strength properties of individual pieces of timber by means of stress-grading rules. This makes possible the

[1] *Loc. cit.*

allocation of safe working loads within narrow limits to each member of a composite timber structure, thereby securing the utmost economy in use of wood. In other words, timber becomes an alternative to steel and concrete in engineering design: the special advantages of each for any particular problem can be accurately weighed. Secondly, the development of timber connectors and modern adhesives overcome one of the major difficulties formerly inherent in timber construction, namely the weakness of the joints or fastenings. Moreover, the modern methods of jointing give joints of calculable efficiency.

The combination of the two factors referred to above has already resulted in great strides being made in the extended constructional use of wood. The future would appear to hinge on the problem of world timber supplies. If a permanent shortage of wood can be avoided the possibilities are immense.

APPENDIX I

NOTE ON DIFFERENTIAL OR ANISOTROPIC SWELLING AND SHRINKAGE OF WOOD

by R. D. Preston, D.Sc., Dept. of Botany, University of Leeds

It is a commonplace that when green wood dries it shrinks, *i.e.*, changes in dimensions, and it has long been known that the dimension changes involved are different in different directions in a wood specimen. Shrinkage is always least along the grain — seldom more than 1 per cent. from green to oven dry — and is always greatest across the grain in the tangential direction (of the order of 15 per cent.) and somewhat less (sometimes as low as 5 per cent.) in the radial direction. At first sight this large transverse shrinkage coupled with a small longitudinal shrinkage might seem natural in a material of this kind, built up as it is, in the main, of long narrow cells arranged with their lengths parallel to, and indeed forming, the grain. A little consideration, however, will show that the dimensions of the cells have no bearing on this phenomenon unless the walls themselves show swelling anisotropy. It is natural, therefore, that attempts made in recent years to define the factors involved in determining anisotropic shrinkage have centred around the structure of the walls of wood cells, so that in order to obtain a clear picture of the issues involved it is necessary first to glance briefly at the modern work on wall structure.

It may be stated briefly that, while the non-cellulosic substances in wood walls have certainly a profound influence on the *degree* of swelling, the *anisotropy* itself is due solely to the presence of cellulose. It is now well known that this polysaccharide is composed of long molecular chains of β-glucose residues bound together by primary valences (Fig. 1*a*) (such as hold together the carbon atoms in diamond). These chains are very long, in a molecular sense, being probably 2000 Å[1] or more in length, depending on the source of the cellulose, as against some 5 Å in width; over certain regions of their length up to 100 or more chains lie close together, strictly parallel to each other

[1] 1 Å = 1/100,000,000 cm.

and spaced quite regularly, forming a small crystal or "crystallite" (the so-called *micelle*) (Fig. 1*b*) some 50 Å in diameter and at least 500 Å long. The micelles are therefore linked by "fringe" chains which bridge the space (the so-called *intermicellar space*) between micelles. It need merely be added that the micelles tend to lie parallel to each other but never achieve accuracy in this respect — they have a *preferred orientation* about which there is an *angular dispersion* which undoubtedly varies from tree to tree, from one region to another within one tree, and indeed from cell to cell and within single

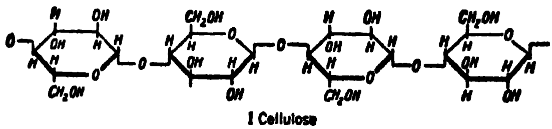


FIG. 1*a*

FIG. 1*a*.—Stereochemical formula of part of a cellulose chain showing four β glucose residues joined together into a linear molecule The chain may be considered to run almost indefinitely to left and right

FIG. 1*b*.—Diagrammatic representation of the "micellar" structure of cellulose. Each line represents a cellulose chain. Heavy lines "micellar" and light lines "intermicellar" regions. Chains are shown ending in micelles though there is no decisive proof that they do so (after Mark)

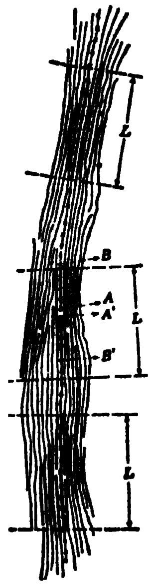


FIG. 1*b*

cells. In oven-dry wood the micelles lie as closely together as the loose chains between them will allow. Their surfaces bristle with -OH groups as do also the chains lying between them, and it is important from the present point of view that these groups — the groups which confer solubility upon glucose for instance — have a strong affinity for water. When water is available it is therefore "attracted" by the micelles, the process being far too complicated to discuss here in detail, moves in between the micelles, the micelles separate and the wood swells. It is clear, therefore, that since the micelles are long and thin, so long that their ends (if any actually exist) can be ignored, then a hypothetical block of cellulose in which the micelles lie strictly parallel will undergo the greatest swelling in directions perpendicular to the micelles' length, and fail to swell at all parallel to it. Real

cellulose swells in the direction of the preferred orientation only because the micelles never lie strictly parallel to each other. The same considerations in reverse clearly apply to shrinkage, so that anisotropy of swelling and shrinkage is thus to be interpreted in terms of an "anisotropy" of structure.

The precise way in which the effect of structure comes to be expressed in wood, however, is still to seek, though the behaviour of isolated wood cells does seem intelligible to some extent from relatively simple considerations. When wood cells are isolated

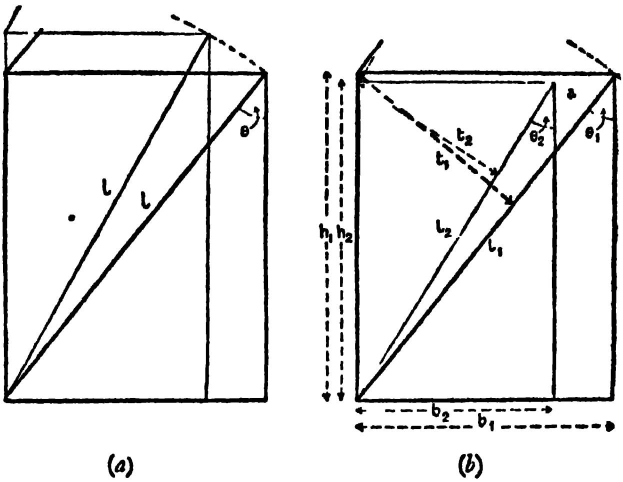


FIG 2.—Diagrammatic representation of part of an elongated cell cut open longitudinally and laid out flat *Thick lines*—normal cell, *thin lines*—cell after dehydration. The oblique line in each case making an angle θ with the longitudinal represents one complete turn of the spiral, so that the length of cell illustrated corresponds to its pitch

(*a*) With the spiral winding constant in length the inclination of the spiral decreases but its pitch increases

(*b*) If the length of the spiral winding decreases also on dehydration, the inclination still decreases, but cell length may also decrease

chemically the walls consist almost solely of cellulose, and complications due to the presence of lignin, which will be mentioned later, are therefore removed. The structure of the wall is still rather complicated, but can be taken, as far as most physical properties are concerned, to consist of a series of micelles inclined at a common angle to the cell length, forming, therefore, a spiral whose windings make some common angle θ to the cell length. If now, such a spirally wound cell shrinks in girth in such a way that the spiral winding itself (parallel to micelle length) does not shrink in length, then the spiral, and therefore the cell, will elongate (Fig. 2 (*a*)). This is the

situation commonly met with in rope. The *fact that* many wood cells do not elongate in this way is explained by the fact that the spiral winding, on account of the angular dispersion of the micelles, does shrink in length and, provided θ is small enough, this shrinkage overrides the elongation due to girth decrease (Fig. 2 *b*). When $\theta = 40°$, however, the two balance so that no change in length occurs, and if $\theta > 40°$ they do in fact elongate on drying. While, however, these simple concepts do give a satisfactory quantitative explanation of shrinkage anisotropy over a limited range of θ, they predict at low values of θ a longitudinal shrinkage which is greater than that observed, and at values of θ much in excess of 40° an elongation greater than that found in practice. Shrinkage even in isolated cells is much more complicated than this simple picture allows and some of the complications undoubtedly involve a dependence of lateral swelling on θ (which will be mentioned later), a possible dependence of the angular dispersion on θ, and a change in dispersion on drying leading to " extra " dimension changes.

Turning now to wood in bulk, a large volume of data has accumulated concerning the shrinkage properties of a number of species in samples taken from different parts of the bole, though much of it refers only to softwoods Transverse shrinkage increases almost linearly with density, while longitudinal shrinkage decreases. Longitudinal shrinkage therefore commonly varies inversely with lateral shrinkage. Considering first the longitudinal-transverse anisotropy, no adequate quantitative explanation has yet been formulated. Early attempts at explanations using relative swelling as a simple vector in terms of wall structure have been rejected on the valid grounds that swelling here cannot be treated in this simple way and leads to a picture of wall structure quite at variance with the facts There is, however, evidence that anisotropic shrinkage and swelling is closely bound up with the structure of the walls of wood cells as expressed by the angle θ defined above (now, of course, the average over the cells constituting the specimen). It may, however, be pertinent to note the source of this evidence. The facts are that longitudinal shrinkage in blocks of wood containing rings near the pith is always higher than elsewhere in the wood and that the average spiral angle θ is always greater in these rings than elsewhere. Similarly, compression wood, in which the angle θ is also unusually great, has correspondingly a high longitudinal shrinkage. In tension wood, however, where θ is exceptionally small, longitudinal shrinkage is nevertheless rather high. It should therefore be noted that conditions here are not quite the same as those obtaining in the case of the

individual cells discussed above, where cells were chosen *from the* same annual ring. Clearly, wood from different annual rings differs in other features as well as in θ — density, perhaps lignin content and distribution, percentage of crystalline cellulose, etc. — and these factors may alter the swelling reactions very considerably.

Not only, however, do the considerations put forward for individual cells fail to give a quantitative explanation for whole wood, but the run of the shrinkage with θ is actually in the opposite direction from that found for cells — longitudinal shrinkage *increases* as θ increases. In trying to resolve this peculiarity two considerations may first be borne in mind. Firstly, it has been found that in the whole wood shrinkage across the grain is itself correlated with θ, and, secondly, in intact wood, the outer wall layer is strongly resistant to swelling and shrinkage, partly due to its particular structure (which remains, of course, in isolated cells) but largely due to its high lignin content. This latter point explains why the cell lumina in wood change very little in size on wetting or drying whereas in isolated cells the change is marked. These considerations can be added to those expressed above for single cells and stated mathematically; the result, however, still fails to give an explanation which is satisfactory even in a qualitative sense except in so far as it does explain the relation between transverse shrinkage and density.

Clearly, something quite fundamental is being overlooked and it does not seem likely that recent attempts to include the (undoubted) slight changes in angular dispersion which occur in shrinkage or swelling, hold any great promise. It seems, in fact, most likely that the clue lies in a most important and fundamental series of papers discussing water sorption in wood largely from a thermodynamical point of view From this work it appears that the outer layer in the wood cell walls, which is most resistant to swelling and shrinkage, causes considerable stresses to be set up in the layers within as the wood is wetted or dried, and it is certain that these stresses must be taken into account in discussing dimension changes. Thus, in general, and somewhat crude terms, a swelling pressure set up in the swelling layer of each cell will cause corresponding elastic, or plastic, extension in the non-swelling layer. At equilibrium, therefore, the swelling pressure is balanced longitudinally by the resistance of the outer layer to further elastic extension; and since the tensile properties of this latter layer in this direction depend on its structure, we have both the pressure causing extension and the resistance opposing it, both functions of structure. The result might well be complicated.

Finally, as regards anisotropy in the transverse plane, again no

agreement has yet been reached. Here there are two possibilities; either the microscopic structure of the wood is the factor involved or the anisotropy is again due to the wall structure. Concerning the first possibility, it was suggested a number of years ago that the phenomenon was associated with the presence of vascular rays which, running radially through the wood, might restrict swelling in this direction. Although doubt has been cast on this explanation on the grounds that the molecular structure in ray cells, as determined in a very few species, is not such as to allow this restrictive influence, it does not seem advisable to dismiss it so lightly. In the second type of explanation it is pointed out that the radial wall of tracheids is structurally different from the tangential wall. Thus the fact that, even in the absence of pits, the structures are different has been used as a possible explanation, though this was later rejected in favour of a mechanism involving the middle lamella. More recently the presence of pits on radial walls only, with their disturbing influence on structure, has been used to explain the smaller radial shrinkage. It is not clear, however, that this can be accepted, since disturbance of molecular orientation would give a smaller lateral swelling only if the general spiral configuration of the tracheids were such as to give lateral swelling higher than a certain minimum. If the spiral were fairly flat, then disturbances in structure caused by pitting might easily cause the swelling to be greater, not smaller, in the radial direction. Until this is looked for, and found, the idea remains only an interesting speculation.

APPENDIX II

LIST OF BOTANICAL EQUIVALENTS OF COMMON OR TRADE NAMES USED IN THE TEXT

NOTE.—In many cases it is not possible to give a single botanical name because the latter is often applied to the timbers of more than one species or even genera; such cases are given below as "spp.", no attempt being made to list all the species that may provide commercial supplies.

abura = *Mitragyna stipulosa* Kuntze
afzelia = *Afzelia* spp
agba = *Gossweilerodendron balsamiferum* Harms
alder = *Alnus glutinosa* Gaertn.
American whitewood, *see* whitewood, American
apitong = *Dipterocarpus* spp. (Philippines)
ash = *Fraxinus* spp.
ash, American = *Fraxinus americana* L., *F. pennsylvanica* var. *lanceolata* Sarg., *F. nigra* Marsh.
ash, European = *Fraxinus excelsior* L.
ash, mountain, *see* oak, Tasmanian
balsa = *Ochroma lagopus* Sw.
beech = *Fagus sylvatica* L.
birch = *Betula* spp.
blackwood, African = *Dalbergia melanoxylon* Guill. et Perr.
blackwood, Australian = *Acacia melanoxylon* R. Br.
box, Cape = *Buxus macowani* Oliv.
box, European = *Buxus sempervirens* L.
boxwood, Ceylon = *Canthium dicoccum* Merr.
brush box = *Tristania conferta* R. Br.
camphorwood, Borneo, *see* kapur
camphorwood, East African = *Ocotea usambarensis* Engl.
camphorwood, Formosan = *Cinnamomum camphora* Nees et Eberm.
canary whitewood, *see* whitewood, American
cedar = *Cedrus* spp.
cedar, Central American = *Cedrela mexicana* Roem.
cedar, cigar-box, *see* cedar, Central American
cedar, South American = *Cedrela* spp. including *C. odorata* L.
cedar, western red = *Thuja plicata* D. Don
chengal = *Balanocarpus Heimii* King

cherry = *Prunus avium* L.
chestnut, American = *Castanea dentata* Borkh.
chestnut, sweet = *Castanea sativa* Mill.
coachwood = *Ceratopetalum apetalum* D. Don
cornel, Turkish = *Cornus* sp.
dahoma = *Piptadenia africana* Hook. f.
deal, Baltic, *see* redwood, European
deal, red, *see* redwood, European
Douglas fir = *Pseudotsuga taxifolia* Brit.
ebony = *Diospyros* spp., *Maba* spp.
ekki—*Lophira alata* var. *procera* (A. Chev.) Burtt Davy
elm = *Ulmus* spp.
elm, common = *Ulmus procera* Salisb.
elm, Dutch = *Ulmus hollandica* var. *major* Rehd.
elm, European = *Ulmus procera* Salisb.
elm, wych = *Ulmus glabra* Hudson (non Miller)
fir = *Abies* spp.
fir, Douglas, *see* Douglas fir
fir, noble = *Abies nobilis* Lindl.
fir, silver = *Abies alba* Mill.
gaboon = *Aucoumea klaineana* Pierre
gedu nohor = *Entandrophragma angolense* C. DC.
greenheart = *Ocotea rodiaei* Mez
guarea = *Guarea cedrata* Pellegr., *G. Thompsonii* Sprague et Hutch.
guarea, scented = *Guarea cedrata* Pellegr.
gum, American red = *Liquidambar styraciflua* L.
gum, spotted = *Eucalyptus maculata* Hook. and *E. citriodora* Hook.
gurjun = *Dipterocarpus* spp. (Andamans, Burma)
hazel = *Corylus avellana* L.
hemlock = *Tsuga* spp.
hemlock, eastern = *Tsuga canadensis* Carr.
hemlock, western = *Tsuga heterophylla* Sarg.
hickory = *Carya* spp. (syn. = *Hicoria* spp.)
holly, American = *Ilex opaca* Ait.
holly, European = *Ilex aquifolium* L.
hornbeam = *Carpinus betulus* L.
idigbo = *Terminalia ivorensis* A. Chev.
iroko = *Chlorophora excelsa* Benth. et Hook. f.
ironbark = *Eucalyptus crebra* F. v. M., *E. paniculata* Sm., *E. siderophloia* Benth., *E. sideroxylon* A. Cunn., *E. fergusoni* R. T. Bak.
ironbark, grey, *see* ironbark
jarrah = *Eucalyptus marginata* Sm.
jelutong = *Dyera costulata* Hook. f.

kapur = *Dryobalanops aromatica* Gaertn. f. (Malaya), *Dryobalanops* spp. (Borneo, Sarawak)
keledang = *Artocarpus lanceifolius* Roxb.
kempas = *Koompassia malaccensis* Maing. ex Benth.
keranji = *Dialium* spp.
keruing = *Dipterocarpus* spp. (Malaya, Borneo)
kokrodua-British Standard name afrormosia = *Afrormosia* sp
larch = *Larix* spp.
larch, European = *Larix decidua* Mill.
lauan = *Shorea* spp., *Pentacme* spp., *Parashorea* spp. (Philippines)
lauan, dark red, *see* lauan
lauan, light red, *see* lauan
lignum vitae = *Guaiacum officinale* L., *G. sanctum* L.
lime = *Tilia vulgaris* Hayne
logwood = *Haematoxylon campechianum* L.
mahogany = *Swietenia* spp.
mahogany, African = *Khaya ivorensis* A. Chev., *K. grandifoliola* C. DC., *K. anthotheca* C. DC.
mahogany, Central American = *Swietenia macrophylla* King
mahogany, cherry, *see* makoré
mahogany, Cuban = *Swietenia mahagoni* Jacq.
mahogany, Gaboon, *see* gaboon
mahogany, Honduras, *see* mahogany, Central American
mahogany, Philippine, *see* lauan
mahogany, sapele, *see* sapele
mahogany, Spanish, *see* mahogany, Cuban
makoré = *Mimusops heckelii* (A. Chev) Hutch et Dalz.
mansonia = *Mansonia altissima* A. Chev.
maple = *Acer* spp.
maple, Pacific = *Acer macrophyllum* Pursh
maple, Queensland = *Flindersia brayleyana* F. v. M, *F. pimenteliana* F. v. M.
maple, rock = *Acer saccharum* Marsh (principally)
melawis = *Gonystylus warburgianus* Gilg.
meranti = *Shorea* spp. (Malaya, Sarawak)
meranti, red = *Shorea* spp. (Malaya, Sarawak)
meranti, white = *Shorea* spp. section *Anthoshorea* Brandis (Malaya)
meranti, yellow = *Shorea* spp. section *Richetia*
merbau = *Intsia palembanica* Baker
mersawa = *Anisoptera* spp. (Malaya)
mountain ash, *see* oak, Tasmanian
mujua = *Alstonia congensis* Engl.
muninga = *Pterocarpus angolensis* DC.

oak = *Quercus* spp.
oak, American red = *Quercus rubra* var. *pagodaefolia* Ashe, *Q. borealis* Michx. f., *Q. borealis* var. *maxima* Sarg., *Q. falcata* Michx., *Q. shumardii* Buckl.
oak, American white = *Quercus alba* L., *Q. montana* Willd., *Q. lyrata* Walt., *Q. prinus* L.
oak, Australian, *see* oak, Tasmanian
oak, Australian silky = *Cardwellia sublimis* F. v. M., *Grevillea robusta* A. Cunn.
oak, Austrian, *see* oak, European
oak, English, *see* oak, European
oak, European = *Quercus robur* L., *Q. petraea* Liebl.
oak, Tasmanian = *Eucalyptus gigantea* Hook. f., *E. obliqua* L'Hérit., *E. regnans* F. v. M.
oak, Turkey = *Quercus cerris* L.
obeche = *Triplochiton scleroxylon* K. Schum.
olive, East African = *Olea hochstetteri* Bak.
opepe = *Sarcocephalus diderrichii* De Wild.
pear = *Pyrus communis* L.
peroba = *Aspidosperma* spp.
persimmon = *Diospyros virginiana* L.
pine, Columbian, *see* Douglas fir
pine, Corsican = *Pinus nigra* var. *calabrica* Schneid.
pine, long-leaf pitch = *Pinus echinata* Mill., *P. palustris* Mill., and *P. taeda* L.
pine, maritime = *Pinus pinaster* Ait.
pine, Oregon, *see* Douglas fir
pine, pitch, *see* pine, long-leaf pitch
pine, Scots = *Pinus sylvestris* L.
pine, white, *see* pine, yellow
pine, yellow = *Pinus strobus* L.
poplar = *Populus* spp.
poplar, black = *Populus nigra* L.
poplar, black Italian = *Populus serotina* (Hybrid)
poplar, Canadian = *Populus tacamahaca* Mill., *P. grandidentata* Michx.
poplar, grey = *Populus canescens* Sm.
poplar, white = *Populus alba* L.
punah = *Tetramerista glabra* Miq.
purpleheart = *Peltogyne* spp.
redwood, *see* redwood, European *and* sequoia
redwood, Baltic, *see* redwood, European
redwood, Californian, *see* sequoia
redwood, European = *Pinus sylvestris* L.

redwood, Kara, *see* redwood, European
rengas = *Melanorrhoea* spp.
resak = *Vatica*, spp. *Cotylelobium* spp. (Malaya)
robinia = *Robinia pseudoacacia* L.
rosewood, Indian = *Dalbergia latifolia* Roxb.
sandalwood = *Santalum album* L.
sapele = *Entandrophragma cylindricum* Sprague and *Entandrophragma* spp.
satin walnut, *see* gum, American red
satinwood, East Indian = *Chloroxylon swietenia* DC.
satinwood, West Indian = *Fagara flava* Krug.
sepul = *Parishia* spp.
sequoia = *Sequoia sempervirens* Endl.
seraya = *Shorea* spp., *Parashorea* spp. (Borneo)
seraya, Borneo white = *Parashorea* spp.
seraya, white = *Shorea* spp., *Parashorea* spp. (Borneo)
sneezewood = *Ptaeroxylon obliquum* (Thunb.) Radlk.
spotted gum, *see* gum, spotted
spruce = *Picea* spp.
spruce, Canadian = *Picea glauca* Voss. (principally)
spruce, European = *Picea abies* Karst.
spruce, Norway, *see* spruce, European
spruce, Sitka = *Picea sitchensis* Carr.
swamp gum, *see* oak, Tasmanian
sycamore = *Acer pseudoplatanus* L.
tali = *Erythrophleum guineense* G. Don. & *E ivorense* A. Chev.
tallowwood = *Eucalyptus microcorys* F. v. M.
Tasmanian oak, *see* oak, Tasmanian
teak = *Tectona grandis* L. f.
tembusu = *Fagraea gigantea* Ridl.
terentang = *Camnosperma* spp.
tulip poplar, *see* whitewood, American
tulip tree, *see* whitewood, American
turpentine = *Syncarpia laurifolia* Ten.
walnut = *Juglans* spp.
walnut, African = *Lovoa klaineana* Pierre ex Sprague
walnut, Australian, *see* walnut, Queensland
walnut, Nigerian, *see* walnut, African
walnut, Queensland = *Endiandra palmerstonii* C. T. White
whitewood = *Picea abies* Karst. and *Abies alba* Mill.
whitewood, American = *Liriodendron tulipifera* L.
whitewood, canary, *see* whitewood, American
willow = *Salix* spp.

willow, crack = *Salix fragilis*
willow, cricket bat = *Salix alba* var. *caerulea* Sm.
willow, white = *Salix alba* L., *S. viridis* Fr.
yang = *Dipterocarpus* spp. (Siam)
yellow poplar, *see* whitewood, American

APPENDIX III

LIST OF THE COMMONER HARDWOOD TREE GENERA WITH THE FAMILIES TO WHICH THEY BELONG

NOTE.—Where possible the families given are for the most part those recognized by Hutchinson.

Acacia — Leguminosae
Acalypha — Euphorbiaceae
Acanthopanax — Araliaceae
Acer — Aceraceae
Achras — Sapotaceae
Acioa — Rosaceae
Ackama — Cunoniaceae
Acradenia — Rutaceae
Acrocarpus — Leguminosae
Acrodiclidium — Lauraceae
Acronychia — Rutaceae
Actinodaphne — Lauraceae
Adenanthera — Leguminosae
Adenodolichos — Leguminosae
Adina — Rubiaceae
Adinandra — Theaceae
Adinobotrys — Millettia
Adiscanthus — Rutaceae
Aegiceras — Myrsinaceae
Aegle — Rutaceae
Aesculus — Sapindaceae or Hippocastanaceae
Aextoxicum — Euphorbiaceae
Afraegle — Rutaceae
Afrolicania — Rosaceae
Afrormosia — Leguminosae
Afzelia — Leguminosae
Agauria — Ericaceae
Agelaea — Connaraceae
Aglaia — Meliaceae
Agonandra — Opiliaceae
Agrostistachys — Euphorbiaceae
Ailanthus — Simaroubaceae
Alangium — Alangiaceae
Albizzia — Leguminosae
Alchornea — Euphorbiaceae
Alchorneopsis — Euphorbiaceae
Aleurites — Euphorbiaceae
Alfaroa — Juglandaceae
Allantoma — Lecythidaceae
Allophylus — Sapindaceae
Alnus — Betulaceae
Alphitonia — Rhamnaceae
Alphonsea — Annonaceae
Alseodaphne — Lauraceae
Alstonia — Apocynaceae
Altingia — Hamamelidaceae
Amanoa — Euphorbiaceae
Amblygonocarpus — Leguminosae
Amoora — Meliaceae
Ampelozizyphus — Rhamnaceae
Amphimas — Leguminosae
Amyris — Burseraceae
Anacardium — Anacardiaceae
Anacolosa — Olacaceae
Anaphalis — Compositae
Andira — Leguminosae
Aneulophus — Erythroxylaceae
Angelesia — Rosaceae
Angophora — Myrtaceae
Angylocalyx — Leguminosae
Aniba — Lauraceae

Anisophyllea — Rhizophoraceae
Anisoptera — Dipterocarpaceae
Annesleа — Theaceae
Annona — Annonaceae
Anodopetalum — Cunoniaceae
Anogeissus — Combretaceae
Anona,[1] see Annona
Anonidium — Annonaceae
Anopyxis — Rhizophoraceae
Anthocephalus — Rubiaceae
Anthocleista — Loganiaceae
Anthostema — Euphorbiaceae
Antiaris — Moraceae
Antidesma — Euphorbiaceae
Antrocaryon — Anacardiaceae
Apeiba — Tiliaceae
Aphanamixis — Meliaceae
Aphananthe — Ulmaceae
Aphania — Sapindaceae
Apodytes — Icacinaceae
Aporosa — Euphorbiaceae
Aporosella — Euphorbiaceae
Aporrhiza — Sapindaceae
Apuleia — Leguminosae
Aquilaria — Thymelaeaceae
Aralia — Araliaceae
Arbutus — Ericaceae
Archytaea — Theaceae
Ardisia — Myrsinaceae
Aromadendron, see Talauma
Artabotrys — Annonaceae
Arthrophyllum — Araliaceae
Artocarpus — Moraceae
Arytera — Sapindaceae
Aspidosperma — Apocynaceae
Asteropeia — Theaceae or Flacourtiaceae
Astronium — Anacardiaceae
Atherosperma — Monimiaceae
Aucoumea — Burseraceae
Aucuba — Cornaceae
Aulacocalyx — Rubiaceae
Auxemma — Boraginaceae
Averrhoa — Oxalidaceae
Avicennia — Verbenaceae
Axinandra — Lythraceae
Azadirachta — Meliaceae
Azara — Flacourtiaceae
Baccaurea — Euphorbiaceae
Backhousia — Myrtaceae
Bagassa — Moraceae
Baikiaea — Leguminosae
Balanites — Simaroubaceae
Balanocarpus — Dipterocarpaceae
Balfourodendron — Rutaceae
Baloghia — Euphorbiaceae
Banara — Flacourtiaceae
Banksia — Proteaceae
Baphia — Leguminosae
Barringtonia — Lecythidaceae
Barteria — Passifloraceae
Barylucuma — Sapotaceae
Bassia — Sapotaceae
Bauhinia — Leguminosae
Bedfordia — Compositae
Beilschmiedia — Lauraceae
Belangera — Cunoniaceae
Belencita — Capparidaceae
Bellota — Lauraceae
Bellucia — Melastomaceae
Bennettia — Flacourtiaceae
Bergsmia — Flacourtiaceae
Berlinia — Leguminosae
Bernouillia — Bombacaceae
Berria, see Berrya
Berrya — Tiliaceae
Bersama — Melianthaceae
Bertholletia — Lecythidaceae
Betula — Betulaceae
Bischofia — Euphorbiaceae
Bixa — Bixaceae
Blepharocarya — Anacardiaceae

[1] Anona and hence Anonaceae is preferred by some botanists to Annona and Annonaceae.

Blighia — Sapindaceae
Blumeodendron — Euphorbiaceae
Bombacopsis — Bombacaceae
Bombax — Bombacaceae
Boschia — Bombacaceae
Boscia — Capparidaceae
Bosquiea — Moraceae
Boswellia — Burseraceae
Bouea — Anacardiaceae
Bougainvillaea, see Buginvillaea
Bowdichia — Leguminosae
Brachylaena — Compositae
Brachystegia — Leguminosae
Bravaisia — Acanthaceae
Bridelia — Euphorbiaceae
Brieya — Annonaceae
Brosimopsis — Moraceae
Brosimum — Moraceae
Broussonetia — Moraceae
Bruguiera — Rhizophoraceae
Bruinsimia — Styracaceae
Brya — Leguminosae
Buchanania — Anacardiaceae
Buchenavia — Combretaceae
Buchholzia — Capparidaceae
Bucida — Combretaceae
Bucklandia — Hamamelidaceae
Buginvillaea — Nyctaginaceae
Bulnesia — Zygophyllaceae
Bumelia — Sapotaceae
Burkea — Leguminosae
Bursera — Burseraceae
Bussea — Leguminosae
Butryospermum — Sapotaceae
Buxus — Buxaceae
Byrsonima — Malpighiaceae
Cabralea — Meliaceae
Cadaba — Capparidaceae
Caesalpinia — Leguminosae
Calatola — Icacinaceae
Caldcluvia — Cunoniaceae
Calderonia — Rubiaceae
Callicoma — Cunoniaceae
Callistermon — Myrtaceae
Callisthene — Vochysiaceae
Calocarpum — Sapotaceae
Caloncoba — Flacourtiaceae
Calophyllum — Guttiferae
Calpocalyx — Leguminosae
Calycogonium — Melastomaceae
Calycophyllum — Rubiaceae
Campnosperma — Anacardiaceae
Canangium — Annonaceae
Canarium — Burseraceae
Canella — Canellaceae
Canthium — Rubiaceae
Cantleya — Icacinaceae
Capparis — Capparidaceae
Caraipa — Guttiferae or Theaceae
Carallia — Rhizophoraceae
Carapa — Meliaceae
Cardwellia — Proteaceae
Careya — Lecythidaceae
Cariniana — Lecythidaceae
Carnarvonia — Proteaceae
Carpinus — Betulaceae
Carpolobia — Polygalaceae
Carpotroche — Flacourtiaceae
Carya — Juglandaceae
Caryocar — Caryocaraceae
Casearia, see Gossypiospermum
Cassia — Leguminosae
Cassine — Celastraceae
Cassipourea — Rhizophoraceae
Castanea — Fagaceae
Castanopsis — Fagaceae
Castanospermum — Leguminosae
Castanospora — Sapindaceae
Castilla — Moraceae
Casuarina — Casuarinaceae
Catalpa — Bignoniaceae
Cathormion — Leguminosae
Cavanillesia — Bombacaceae
Ceanothus, see Zizyphus
Cecropia — Moraceae
Cedrela — Meliaceae

Ceiba — Bombacaceae
Celastrus — Celastraceae
Celtis — Ulmaceae
Centrolobium — Leguminosae
Cephalosphaera — Myristicaceae
Ceratopetalum — Cunoniaceae
Cerbera — Apocynaceae
Cereus — Cactaceae
Ceriops — Rhizophoraceae
Cespedesia — Ochnaceae
Chaetachne — Ulmaceae
Chaetocarpus — Euphorbiaceae
Champereia — Opiliaceae
Chaunochiton — Olacaceae
Cheilosa — Euphorbiaceae
Cheirodendron — Araliaceae
Chenolea — Chenopodiaceae
Chickrassia, see Chukrasia
Chidlowia — Leguminosae
Chilopsis — Bignoniaceae
Chionanthus, see Linociera
Chisocheton — Meliaceae
Chlorophora — Moraceae
Chloroxylon — Rutaceae or Meliaceae
Chorisia — Bombacaceae
Chromolucuma — Sapotaceae
Chrysobalanus — Rosaceae
Chrysophyllum — Sapotaceae
Chukrasia — Meliaceae
Chydenanthus — Lecythidaceae
Chytranthus — Sapindaceae
Chytroma — Lecythidaceae
Cinnamodendron — Canellaceae
Cinnamomum — Lauraceae
Cinnamosma — Canellaceae
Cistanthera — Tiliaceae
Citharexylum — Verbenaceae
Citrus — Rutaceae
Clarisia — Moraceae
Clausena — Rutaceae
Cleidion — Euphorbiaceae
Cleistanthus — Euphorbiaceae
Cleistopholis — Annonaceae
Clusia — Guttiferae
Cococeras — Euphorbiaceae
Coccoloba — Polygonaceae
Coccolobis, see Coccoloba
Cochlospermum — Bixaceae
Coelocaryon — Myristicaceae
Coelostegia — Bombacaceae
Coffea — Rubiaceae
Cola — Sterculiaceae
Colletia — Rhamnaceae
Colubrina — Rhamnaceae
Columbia — Tiliaceae
Combretocarpus — Rhizophoraceae
Combretodendron — Lecythidaceae or Combretaceae
Combretum — Combretaceae
Commersonia — Sterculiaceae
Commiphora — Burseraceae
Comocladia — Anacardiaceae
Compsoneura — Myristicaceae
Condalia — Rhamnaceae
Connaropsis — Oxalidaceae
Conocarpus — Combretaceae
Conomorpha — Myrsinaceae
Conopharyngia — Apocynaceae
Copaifera — Leguminosae
Cordia — Boraginaceae
Cordyla — Leguminosae
Cornus — Cornaceae
Corylus — Corylaceae or Betulaceae
Corynanthe — Rubiaceae
Cotinus — Anacardiaceae
Cotylelobium — Dipterocarpaceae
Couepia — Rosaceae
Coula — Olacaceae
Couma — Apocynaceae
Couratari — Lecythidaceae
Couroupita — Lecythidaceae
Coussapoa — Moraceae
Crataegus — Rosaceae

Crataeva — Capparidaceae
Cratoxylon — Guttiferae
Crescentia — Bignoniaceae
Crossopteryx — Rubiaceae
Crossostylis — Rhizophoraceae
Croton — Euphorbiaceae
Crudia — Leguminosae
Crypteronia — Crypteroniaceae
Cryptocarya — Lauraceae
Ctenolophon — Linaceae or Olacaceae
Cudrania — Moraceae
Cunonia — Cunoniaceae
Curatella — Dilleniaceae
Curtisia — Cornaceae
Cussonia — Araliaceae
Cyathocalyx — Annonaceae
Cybianthus — Myrsinaceae
Cyclostemon — Euphorbiaceae
Cylicodiscus — Leguminosae
Cynometra — Leguminosae
Dacryodes — Burseraceae
Dalbergia — Leguminosae
Dalbergiella — Leguminosae
Daniella — Leguminosae
Daphnandra — Monimiaceae
Daphniphyllum — Euphorbiaceae
Daphnopsis — Thymelaeaceae
Dehaasia — Lauraceae
Deinbollia — Sapindaceae
Dennettia — Annonaceae
Deplanchea — Bignoniaceae
Derris — Leguminosae
Desbordesia — Simaroubaceae
Desmostachys — Icacinaceae
Desplatzia — Tiliaceae
Detarium — Leguminosae
Dialium — Leguminosae
Dialyanthera — Myristicaceae
Dichrostachys — Leguminosae
Dicorynia — Leguminosae
Dicranolepis — Thymelaeaceae
Dictyandra — Rubiaceae
Didelotia — Leguminosae
Didymopanax — Araliaceae
Dillenia — Dilleniaceae
Dilodendron — Sapindaceae
Dimorphandra — Leguminosae
Dimorphocalyx — Euphorbiaceae
Diospyros — Ebenaceae
Diphysa — Leguminosae
Diplodiscus — Tiliaceae
Diploglottis — Sapindaceae
Diplospora — Rubiaceae
Diplotropis — Leguminosae
Dipterocarpus — Dipterocarpaceae
Dipteryx — Leguminosae
Dirca — Thymelaeaceae
Discaria — Rhamnaceae
Discoglypremna — Euphorbiaceae
Discophora — Icacinaceae
Dissomeria — Flacourtiaceae or Samydaceae
Distemonanthus — Leguminosae
Dodonaea — Sapindaceae
Doerpfeldia — Rhamnaceae
Dolichandrone — Bignoniaceae
Dombeya — Sterculiaceae
Doona — Dipterocarpaceae
Dorpyhora — Monimiaceae
Dracontomelum — Anacardiaceae
Drepananthus — Annonaceae
Drimycarpus — Anacardiaceae
Drimys — Magnoliaceae
Dryobalanops — Dipterocarpaceae
Drypetes — Euphorbiaceae
Duabanga — Sonneratiaceae
Duboscia — Tiliaceae
Duguetia — Annonaceae
Durio — Bombacaceae
Dyera — Apocynaceae
Dysoxylum — Meliaceae
Echinocarpus — Elaeocarpaceae

Echiochilon — Boraginaceae
Echirospermum — Leguminosae
Ehretia — Boraginaceae
Ekebergia — Meliaceae
Elaeocarpus — Elaeocarpaceae
Elaeodendron — Celastraceae
Elaeophorbia — Euphorbiaceae
Elateriospermum — Euphorbiaceae
Emblica — Euphorbiaceae
Embothrium — Proteaceae
Enantia — Annonaceae
Endiandra — Lauraceae
Endospermum — Euphorbiaceae
Engelhardtia — Juglandaceae
Enicosanthum — Annonaceae
Entada — Leguminosae
Entandrophragma — Meliaceae
Enterolobium — Leguminosae
Eperua — Leguminosae
Eremophila — Myoporaceae
Eriobotrya — Rosaceae
Eriocoelum — Sapindaceae
Eriodendron, see Ceiba
Erioglossum — Sapindaceae
Erisma — Vochysiaceae
Ervatamia — Apocynaceae
Erythrina — Leguminosae
Erythrophloeum — Leguminosae
Erythropsis — Sterculiaceae
Erythroxylon, see Erythroxylum
Erythroxylum — Erythroxylaceae
Eschweilera — Lecythidaceae
Esenbeckia — Rutaceae
Eucalyptus — Myrtaceae
Eucryphia — Eucryphiaceae or Rosaceae
Eugenia — Myrtaceae
Euonymus — Celastraceae
Eupatorium — Compositae
Euphorbia — Euphorbiaceae
Euroschinus — Anacardiaceae
Eurya — Theaceae
Eusideroxylon — Lauraceae
Euxylophora — Rutaceae
Evodia — Rutaceae
Evonymus, see Euonymus
Exandra — Rubiaceae
Excoecaria — Euphorbiaceae
Exocarpus — Santalaceae
Eysenhardtia — Leguminosae
Fagara — Rutaceae
Fagraea — Loganiaceae
Fagus — Fagaceae
Faurea — Proteaceae
Fegimanra — Anacardiaceae
Ferolia — Rosaceae
Ferreirea — Leguminosae
Ficus — Moraceae
Fillaeopsis — Leguminosae
Firmiana — Sterculiaceae
Flacourtia — Flacourtiaceae
Flindersia — Rutaceae or Meliaceae
Fluggea — Euphorbiaceae
Foetidia — Lecythidaceae
Fontanesia — Oleaceae
Forsythia — Oleaceae
Fraxinus — Oleaceae
Funifera — Thymelaeaceae
Funtumia — Apocynaceae
Fusanus — Santalaceae
Gaertnera — Loganiaceae
Gallesia — Phytolaccaceae
Ganophyllum — Sapindaceae
Ganua — Sapotaceae
Garcinia — Guttiferae
Gardenia — Rubiaceae
Garuga — Burseraceae
Geasonia — Rubiaceae
Geijera — Rutaceae
Geissois — Cunoniaceae
Genipa — Rubiaceae
Gilibertia — Araliaceae
Gleditschia, see Gleditsia
Gleditsia — Leguminosae

Glochidion — Euphorbiaceae
Gluema — Sapotaceae
Gluta — Anacardiaceae
Glycosmis — Rutaceae
Glycoxylon — Sapotaceae
Glyphaea — Tiliaceae
Gmelina — Verbenaceae
Gochnatia — Compositae
Goeldinia — Lecythidaceae
Gomphia, see Ouratea
Gonioma — Apocynaceae
Gonystylus — Gonystylaceae
Gordonia — Theaceae
Gossweilerodendron — Leguminosae
Gossypiospermum — Flacourtiaceae
Goupia — Goupiaceae
Grevillea — Proteaceae
Grewia — Tiliaceae
Grias — Lecythidaceae
Guaiacum — Zygophyllaceae
Guarea — Meliaceae
Guatteria — Annonaceae
Guazuma — Sterculiaceae
Guettarda — Rubiaceae
Guevina — Proteaceae
Guiera — Combretaceae
Guioa — Sapindaceae
Gustavia — Lecythidaceae
Gyminda — Celastraceae
Gymnacranthera — Myristicaceae
Gymnanthes — Euphorbiaceae
Gymnocladus — Leguminosae
Gymnosporia — Celastraceae
Gynocardia — Flacourtiaceae
Gynotroches — Rhizophoraceae
Gyranthera — Bombacaceae
Gyrocarpus — Hernandiaceae
Haematoxylon — Leguminosae
Hakea — Proteaceae
Halfordia — Rutaceae
Haloxylon — Chenopodiaceae
Hamamelis — Hamamelidaceae
Hampea — Bombacaceae
Hancornia — Apocynaceae
Hannoa — Simaroubaceae
Haploclathra — Guttiferae
Haplormosia — Leguminosae
Hardwickia — Leguminosae
Harmandia — Olacaceae
Harpullia — Sapindaceae
Harungana — Hypericaceae
Hasseltia — Flacourtiaceae
Hedera — Araliaceae
Hedwigia — Burseraceae
Hedycarya — Monimiaceae
Heeria — Anacardiaceae
Heinsia — Rubiaceae
Heisteria — Olacaceae
Helicia — Proteaceae
Helicostylis — Moraceae
Helietta — Rutaceae
Heliocarpus — Tiliaceae
Heliotrium — Boraginaceae
Hennecartia — Monimiaceae
Henoonia — Sapotaceae
Henriettella — Melastomaceae
Heritiera — Sterculiaceae
Hernandia — Hernandiaceae
Heterodendron — Sapindaceae
Heterophragma — Bignoniaceae
Heterotrichum — Melastomaceae
Hevea — Euphorbiaceae
Hexalobus — Annonaceae
Hibiscus — Malvaceae
Hicoria, see Carya
Hieronymia — Euphorbiaceae
Hippomane — Euphorbiaceae
Hirtella — Rosaceae
Holarrhena — Apocynaceae
Holocalyx — Leguminosae
Holoptelea — Ulmaceae
Homalium — Samydaceae or Flacourtiaceae
Hopea — Dipterocarpaceae

Horsfieldia — Myristicaceae
Humiria — Humiriaceae
Hunteria — Apocynaceae
Hura — Euphorbiaceae
Hydnocarpus — Flacourtiaceae
Hymenaea — Leguminosae
Hymenocardia — Euphorbiaceae
Hymenodictyon — Rubiaceae
Hymenolobium — Leguminosae
Hymenostegia — Leguminosae
Hypodaphnis — Lauraceae
Ichthyomethia — Leguminosae
Ilex — Aquifoliaceae
Illicium — Winteraceae
Inga — Leguminosae
Intsia — Leguminosae
Irvingia — Simaroubaceae
Iryanthera — Myristicaceae
Isoberlinia — Leguminosae
Isolona — Annonaceae
Itea — Escalloniaceae
Iteadaphne — Lauraceae
Ixonanthes — Erythroxylaceae
Ixora — Rubiaceae
Jacaranda — Bignoniaceae
Jackia — Rubiaceae
Jacquinia — Myrsinaceae
Jasminum — Oleaceae
Jatropha — Euphorbiaceae
Joanesia — Euphorbiaceae
Jugastrum — Lecythidaceae
Juglans — Juglandaceae
Kandelia — Rhizophoraceae
Karwinski — Rhamnaceae
Kayea — Guttiferae
Khaya — Meliaceae
Kibara — Monimiaceae
Kibatalia, see Kickxia
Kibessia — Melastomaceae
Kickxia — Apocynaceae
Kigelia — Bignoniaceae
Kiggelaria — Flacourtiaceae
Killmevera — Guttiferae
Klainedoxa — Simaroubaceae
Kleinhovia — Sterculiaceae
Knema — Myristicaceae
Koordersiodendron — Anacardiaceae
Koompassia — Leguminosae
Krugiodendron — Rhamnaceae
Kunstlerodendron — Euphorbiaceae
Kurrimia — Celastraceae
Labatia — Sapotaceae
Labourdonnaisia — Sapotaceae
Laburnum — Leguminosae
Lachnopylis — Loganiaceae
Laetia — Flacourtiaceae
Lagerstroemia — Lythraceae
Lagetta — Thymelaeaceae
Laguncularia — Combretaceae
Lannea — Anacardiaceae
Lansium — Meliaceae
Laportea — Urticaceae
Lasiodiscus — Rhamnaceae
Laurelia — Monimiaceae
Lecaniodiscus — Sapindaceae
Lecythis — Lecythidaceae
Leea — Ampelidaceae
Lepisanthes — Sapindaceae
Leptactina — Rubiaceae
Leptanlus — Icacinaceae
Leptospermum — Myrtaceae
Leucadendron — Proteaceae
Licania — Rosaceae
Licaria — Lauraceae
Lichnophora — Compositae
Ligustrum — Oleaceae
Lindackeria — Flacourtiaceae
Lindera — Lauraceae
Linociera — Oleaceae
Liquidambar — Hamamelidaceae
Liriodendron — Magnoliaceae
Liriosma — Olacaceae
Lithospermum — Boraginaceae
Litsea — Lauraceae

Loesnera — Leguminosae
Lomatia — Proteaceae
Lonchocarpus — Leguminosae
Lophira — Ochnaceae
Lophopetalum — Celastraceae
Lovoa — Meliaceae
Loxopterygium — Anacardiaceae
Lucuma — Sapotaceae
Luehea — Tiliaceae
Lumnitzera — Combretaceae
Lunania — Flacourtiaceae
Lunasia — Rutaceae
Lysicarpus — Myrtaceae
Lysiloma — Leguminosae
Maba — Ebenaceae
Mabea — Euphorbiaceae
Macadamia — Proteaceae
Macaranga — Euphorbiaceae
Macarisia — Rhizophoraceae
Machaerium — Leguminosae
Machilus — Lauraceae
Maclura — Moraceae
Macrodendron — Cunoniaceae
Macrolobium — Leguminosae
Madhuca — Sapotaceae
Maerua — Capparidaceae
Maesa — Myrsinaceae
Maesobotrya — Euphorbiaceae
Maesopsis — Rhamnaceae
Magnolia — Magnoliaceae
Magonia — Sapindaceae
Maingaya — Hamamelidaceae
Malacantha — Sapotaceae
Mallotus — Euphorbiaceae
Malus — Rosaceae
Mammea — Guttiferae
Mangifera — Anacardiaceae
Manihot — Euphorbiaceae
Manilkara — Sapotaceae
Mannia — Simaroubaceae
Mansonia — Sterculiaceae
Mappa — Icacinaceae
Mareya — Euphorbiaceae
Markhamia — Bignoniaceae
Marquesia — Dipterocarpaceae
Mastixia — Cornaceae
Matisia — Bombacaceae
Mayna — Flacourtiaceae
Maytenus — Celastraceae
Melaleuca — Myrtaceae
Melanochyla — Anacardiaceae
Melanorrhoea — Anacardiaceae
Melanoxylon — Leguminosae
Melia — Meliaceae
Melicocca — Sapindaceae
Meliosma — Sabiaceae
Melochia — Sterculiaceae
Memecylon — Melastomaceae
Merrillia — Rutaceae
Mesua — Guttiferae
Metopium — Anacardiaceae
Mezzettia — Annonaceae
Michelia — Magnoliaceae
Miconia — Melastomaceae
Microcos — Tiliaceae
Microdesmis — Euphorbiaceae
Micromelum — Rutaceae
Micropholis — Sapotaceae
Miliusa — Annonaceae
Millettia — Leguminosae
Mimosa — Leguminosae
Mimusops — Sapotaceae
Minquartia — Olacaceae
Misanteca — Lauraceae
Mischocarpus — Sapindaceae
Mitragyna — Rubiaceae
Mitrephora — Annonaceae
Mollinedia — Monimiaceae
Monimia — Monimiaceae
Monodora — Annonaceae
Monopetalanthus — Bignoniaceae
Monotes — Dipterocarpaceae
Montanoa — Compositae
Moquinia — Compositae
Mora — Leguminosae
Morelia — Rubiaceae

Morinda — Rubiaceae
Moringa — Moringaceae
Morisonia — Capparidaceae
Moronobea — Guttiferae
Morquilea — Rosaceae
Morus — Moraceae
Mosquitoxyllum — Anacardiaceae
Mouriria — Melastomaceae
Murraya — Rutaceae
Musanga — Moraceae
Musgravea — Proteaceae
Mussaendopsis — Rubiaceae
Myoporum — Myoporaceae
Myrcia — Myrtaceae
Myrianthus — Moraceae
Myristica — Myristicaceae
Myrocarpus — Leguminosae
Myrospermum — Leguminosae
Myroxylon — Leguminosae
Myrsine — Myrsinaceae
Napeodendron — Sapindaceae
Napoleona — Lecythidaceae
Nauclea — Rubiaceae
Necespia — Euphorbiaceae
Nectandra, see Ocotea
Neesia — Bombacaceae
Neonauclea — Rubiaceae
Neoscortechinia — Euphorbiaceae
Neostenanthera — Annonaceae
Nephelium — Sapindaceae
Newbouldia — Bignoniaceae
Niebuhria — Capparidaceae
Norrisia — Loganiaceae
Nothofagus — Fagaceae
Nothophoebe — Lauraceae
Nuxia — Loganiaceae
Nuxia (most spp.), see Lachnopylis
Nyssa — Nyssaceae
Ochanostachys — Olacaceae
Ochna — Ochnaceae
Ochrocarpus — Guttiferae
Ochroma — Bombacaceae
Ocotea — Lauraceae
Octoknema — Octoknemataceae
Octomeles — Datiscaceae
Odina, see Lannea
Olax — Olacaceae
Oldfieldia — Euphorbiaceae
Olea — Oleaceae
Olearia — Compositae
Olinia — Oliniaceae
Olmedia — Moraceae
Omphalocarpum — Sapotaceae
Oncoba — Flacourtiaceae
Ongokea — Olacaceae
Oreodaphne — Lauraceae
Orites — Proteaceae
Ormosia — Leguminosae
Osmanthus — Oleaceae
Ostodes — Euphorbiaceae
Ostrya — Betulaceae or Corylaceae
Ostryoderris — Leguminosae
Otophora — Sapindaceae
Ougeinia — Leguminosae
Ouratea — Ochnaceae
Ovidia — Thymelaeaceae
Owenia — Meliaceae
Oxandra — Annonaceae
Oxystigma — Leguminosae
Oxytheca — Sapotaceae
Pachira — Bombacaceae
Pachyelsma — Leguminosae
Pachylobus — Burseraceae
Pachypodanthium — Annonaceae
Pachystela — Sapotaceae
Pajanelia — Bignoniaceae
Palaquium — Sapotaceae
Panax, see Tieghemopanax
Pancheria — Cunoniaceae
Panda — Pandaceae
Pangium — Flacourtiaceae
Paralabatia — Sapotaceae
Paramignya — Rutaceae
Parashorea — Dipterocarpaceae

Parastemon — Rosaceae
Paratecoma — Bignoniaceae
Paravallaris — Apocynaceae
Parinari — Rosaceae
Parinarium, see Parinari
Parishia — Anacardiaceae
Parkia — Leguminosae
Paropsia — Passifloraceae
Pasania — Fagaceae
Patagonula — Boraginaceae
Patrisia — Flacourtiaceae
Paulownia — Scrophulariaceae
Pausinystalia — Rubiaceae
Payena — Sapotaceae
Pellacalyx — Rhizophoraceae
Peltogyne — Leguminosae
Peltophorum — Leguminosae
Pentace — Tiliaceae
Pentaclethra — Leguminosae
Pentacme — Dipterocarpaceae
Pentadesma — Guttiferae
Pentapanax — Araliaceae
Pentaphylax — Theaceae
Pentaspadon — Anacardiaceae
Pera — Euphorbiaceae
Perebea — Moraceae
Pereskia — Cactaceae
Persea — Lauraceae
Perymenium — Compositae
Petitia — Verbenaceae
Peumus — Monimiaceae
Phebalium — Rutaceae
Phialodiscus — Sapindaceae
Phoebe — Lauraceae
Photinia — Rosaceae
Phyllanthus — Euphorbiaceae
Phyllostylon — Ulmaceae
Physocalymma — Lythraceae
Phytolacca — Phytolaccaceae
Picraena — Simaroubaceae
Picralima — Apocynaceae
Picrasma — Simaroubaceae
Pilocarpus — Rutaceae
Pimeleodendron — Euphorbiaceae
Pimenta — Myrtaceae
Pinckneya — Rubiaceae
Piptadenia — Leguminosae
Piptocarpha — Compositae
Piranhea — Euphorbiaceae
Piratinera, see Brosimum
Piscidia, see Ichthyomethia
Pisonia — Nyctaginaceae
Pistacia — Anacardiaceae
Pithecellobium — Leguminosae
Pithecolobium, see Pithecellobium
Pittosporum — Pittosporaceae
Placodiscus — Sapindaceae
Planchonella — Sapotaceae
Planchoria — Lecythidaceae
Planera — Ulmaceae
Platanus — Platanaceae
Plathymenia — Leguminosae
Platonia — Leguminosae
Platycarya — Juglandaceae
Platycyamus — Leguminosae
Platylophus — Cunoniaceae
Platymiscium — Leguminosae
Platymitra — Annonaceae
Platypodium — Leguminosae
Pleiocarpa — Apocynaceae
Pleiococca — Rutaceae
Pleiogynium — Anacardiaceae
Pleodendron — Canellaceae
Pleurostylia — Celastraceae
Plumeria — Apocynaceae
Poeciloneuron — Guttiferae
Poga — Rhizophoraceae
Polyalthia — Annonaceae
Polygala — Polygalaceae
Polyosma — Escalloniaceae
Polyscias — Araliaceae
Pometia — Sapindaceae
Pongamia — Leguminosae
Popowia — Annonaceae
Populus — Salicaceae

Poraqueiba — Icacinaceae
Porlieria — Zygophyllaceae
Pouteria — Sapotaceae
Pradosia — Sapotaceae
Prainea — Moraceae
Premna — Verbenaceae
Prioria — Leguminosae
Prockia — Flacourtiaceae
Prosopis — Leguminosae
Protea — Proteaceae
Protium — Burseraceae
Protomegabaria — Euphorbiaceae
Prunus — Rosaceae
Pseudocedrela — Meliaceae
Pseudomorus — Moraceae
Pseudosamanea — Leguminosae
Pseudospondias — Anacardiaceae
Psidium — Myrtaceae
Ptaeroxylon — Meliaceae
Pteleocarpa — Cardiopteridaceae
Pternandra — Melastomaceae
Pterocarpus — Leguminosae
Pterocymbium — Sterculiaceae
Pterogyne — Leguminosae
Pterospermum — Sterculiaceae
Pterygota — Sterculiaceae
Ptychopetalum — Olaceae
Ptychopyxis — Euphorbiaceae
Punica — Punicaceae
Pycnanthus — Myristicaceae
Pygeum — Rosaceae
Pyrenaria — Theaceae
Pyrus — Rosaceae
Qualea — Vochysiaceae
Quararibea — Bombacaceae
Quassia — Simaroubaceae
Quebrachia, see Schinopsis
Quercus — Fagaceae
Quillaja — Rosaceae
Quintinia — Saxifragaceae
Randia — Rubiaceae
Rapanea — Myrsinaceae
Rauwolfia — Apocynaceae
Reevesia — Sterculiaceae
Reynosia — Rhamnaceae
Rhamnidium — Rhamnaceae
Rhamnus — Rhamnaceae
Rheedia — Guttiferae
Rhizophora — Rhizophoraceae
Rhodamnia — Myrtaceae
Rhodoleia — Hamamelidaceae
Rhodosphaera — Anacardiaceae
Rhus — Anacardiaceae
Ricinodendron — Euphorbiaceae
Ricinus — Euphorbiaceae
Rinorea — Violaceae
Robinia — Leguminosae
Rollinia — Annonaceae
Roupala — Proteaceae
Ruprechtia — Polygonaceae
Ryparosa — Flacourtiaceae
Sabia — Sabiaceae
Saccopetalum — Annonaceae
Sacoglottis — Humiriaceae
Sacrosperma — Sapotaceae
Sageraea — Annonaceae
Sageretia — Rhamnaceae
Salacia — Hippocrateaceae
Salix — Salicaceae
Salvadora — Salvadoraceae
Salvertia — Vochysiaceae
Sambucus — Caprifoliaceae
Sandoricum — Meliaceae
Santalum — Santalaceae
Santiria — Burseraceae
Sapindus — Sapindaceae
Sapium — Euphorbiaceae
Saraca — Leguminosae
Sarcocephalus — Rubiaceae
Sarcomphalus — Rhamnaceae
Sassafras — Lauraceae
Saurauia — Saurauiaceae
Scalesia — Compositae
Scaphium — Sterculiaceae
Scaphopetalum — Sterculiaceae
Schaefferia — Celastraceae

Schefflera — Araliaceae
Schima — Theaceae
Schinopsis — Anacardiaceae
Schinus — Anacardiaceae
Schizolobium — Leguminosae
Schizomeria — Cunoniaceae
Schleichera — Sapindaceae
Schoepfia — Olacaceae
Schotia — Leguminosae
Schoutenia — Tiliaceae
Schrebera — Oleaceae
Schumanniophyton — Rubiaceae
Sciadodendron — Araliaceae
Sclerocarya — Anacardiaceae
Scolopia — Flacourtiaceae
Scorodocarpus — Olacaceae
Scottellia — Flacourtiaceae
Scutinanthe — Burseraceae
Scyphiphora — Rubiaceae
Scytopetalum — Scytopetalaceae
Sebastiana — Euphorbiaceae
Securidaca — Polygalaceae
Semecarpus — Anacardiaceae
Sersalisia — Sapotaceae
Shorea — Dipterocarpaceae
Sickingia — Rubiaceae
Sideroxylon — Sapotaceae
Silvia — Lauraceae
Simarouba — Simaroubaceae
***Simaruba*, see Simarouba**
Sindora — Leguminosae
Siparuna — Monimiaceae
Siphonodon — Celastraceae
Skimmia — Rutaceae
Sloanea — Elaeocarpaceae
Sloetia — Moraceae
Smeathmannia — Passifloraceae
Sonneratia — Sonneratiaceae
Soyauxia — Passifloraceae
Spathodea — Bignoniaceae
Spiraeopsis — Cunoniaceae
Spirostachys — Euphorbiaceae
Spondianthus — Anacardiaceae
Spondias — Anacardiaceae
Staudtia — Myristicaceae
Stemonocoleus — Leguminosae
Stemonurus — Icacinaceae
Stenocarpus — Proteaceae
Sterculia — Sterculiaceae
Stereospermum — Bignoniaceae
Sterigmapetalum — Rhizophoraceae
Stewartia — Theaceae
Strephonema — Combretaceae
Strombosia — Olacaceae
Strychnos — Loganiaceae
Stylocoryna — Rubiaceae
Styrax — Styracaceae
Suriana — Surianaceae or Simaroubaceae
Swartzia — Leguminosae
Sweetia — Leguminosae
Swietenia — Meliaceae
Swintonia — Anacardiaceae
Sycopsis — Hamamelidaceae
Sygyiopsis — Sapotaceae
Symphonia — Guttiferae
Symplocos — Symplocaceae
Syncarpia — Myrtaceae
Synoum — Meliaceae
Synsepalum — Sapotaceae
Syringa — Oleaceae
Syzygium — Myrtaceae
Tabebuia — Bignoniaceae
Tabernaemontana — Apocynaceae
Talauma — Magnoliaceae
Talbotiella — Leguminosae
Tamarindus — Leguminosae
Tamarix — Tamaricaceae
Tapiria — Anacardiaceae
***Taraktogenos*, see Hydnocarpus**
Tarrietia — Sterculiaceae
Taxotrophis — Moraceae
Teclea — Rutaceae
Tecoma — Bignoniaceae

Tectona — Verbenaceae
Terminalia — Combretaceae
Ternstroemia — Theaceae
Tessaria — Compositae
Tetracentron — Magnoliaceae
Tetragastris — Burseraceae
Tetrameles — Datiscaceae
Tetramerista — Marcgraviaceae
Tetrapleura — Leguminosae
Theobroma — Sterculiaceae
Thespesia — Malvaceae
Tibouchina — Melastomaceae
Tieghamopanax — Anacardiaceae
Tilia — Tiliaceae
Timonius — Rubiaceae
Tipuana — Leguminosae
***Toona*, see Cedrela**
Torresea — Leguminosae
Torricellia — Cornaceae
Tournefortia — Boraginaceae
***Toxylon*, see Maclura**
Trachylobium — Leguminosae
Treculia — Moraceae
Trema — Ulmaceae
Trewia — Euphorbiaceae
Trichadenia — Flacourtiaceae
Trichanthera — Acanthaceae
Trichilia — Meliaceae
Trichoscypha — Anacardiaceae
Trichospermum — Tiliaceae
Trigoniastrum — Trigoniaceae
Trigonopleura — Euphorbiaceae
Triomma — Burseraceae
Triplaris — Polygonaceae
Triplochiton — Sterculiaceae
Tristania — Myrtaceae
Tristira — Sapindaceae
Trochodendron — Magnoliaceae
Turraea — Meliaceae
Turraeanthus — Meliaceae
Tylostemon — Lauraceae
Uapaca — Euphorbiaceae
Ulmus — Ulmaceae
Umbellularia — Lauraceae
Unonopsis — Annonaceae
Upuna — Dipterocarpaceae
Urandra — Icacinaceae
Urophyllum — Rubiaceae
Uvaria — Annonaceae
Uvariastrum — Annonaceae
Vantanea — Humiriaceae
Vateriopsis — Dipterocarpaceae
Vatica — Dipterocarpaceae
Vernonia — Compositae
Viburnum — Caprifoliaceae
Villaresia — Icacinaceae
Virola — Myristicaceae
Vismia — Hypericaceae
Vitex — Verbenaceae
Vochysia — Vochysiaceae
Vouacapoua — Leguminosae
Wallenia — Myrsinaceae
Warburgia — Canellaceae
Weihea — Rhizophoraceae
Weinmannia — Cunoniaceae
Wetria — Euphorbiaceae
Wormia — Dilleniaceae
Wrightia — Apocynaceae
Xanthophyllum — Polygalaceae
Xanthostemon — Myrtaceae
Xerospermum — Sapindaceae
Ximenia — Olacaceae
Xylia — Leguminosae
Xylocarpus — Meliaceae
Xylomelum — Proteaceae
Xylopia — Annonaceae
Xylosma — Flacourtiaceae
Xymalos — Monimiaceae
Zanha — Burseraceae
Zanthoxylum — Rutaceae
Zelkova — Ulmaceae
Zizyphus — Rhamnaceae
Zollernia — Leguminosae
Zuelania — Flacourtiaceae
Zygogynum — Magnoliaceae

INDEX

THE END

PRINTED BY R. & R. CLARK, LTD., EDINBURGH